PB86-141785

Study of Gasoline Volatility and Hydrocarbon Emissions from Motor Vehicles

(U.S.) Environmental Protection Agency
Ann Arbor, MI

Nov 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-141785

EPA-AA-SDSB-85-5

Study of Gasoline Volatility and Hydrocarbon Emissions from Motor Vehicles

November 1985

Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Sources
Office of Air and Radiation
U. S. Environmental Protection Agency

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-AA-SDSB-85-5	2.	3. RECIPIENT'S ACCESSION NO. PB86 141785/AS
4. TITLE AND SUBTITLE Study of Gasoline Volatility and Hydrocarbon Emissions From Motor Vehicles		5. REPORT DATE November 1985
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Office of Mobile Sources Standards Development and Support Branch Ann Arbor, MI 48105		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED Technical
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

In-use motor vehicle evaporative hydrocarbon emissions greatly exceed their applicable EPA emission standards. The primary reason is that the volatility of commercial gasoline is substantially greater than that of the certification test fuel specified by EPA (i.e., vehicles are simply not designed to handle the fuel volatility they regularly experience).

The long-term solution is to equate the volatilities of commerical and certification test gasolines. This can be done at: 1) the current volatiltiy of commerical gasoline, 2) that of certification test gasoline, or 3) at some point in between. However, in the short term, only the reduction of commerical gasoline volatility has a significant environmental benefit, since the effect of certification fuel modifications must await the turnover of the vehicle fleet. This study examines the technological feasibility, costs, emission reductions, air quality impacts and cost effectiveness of the various long-term and short-term solutions to this problem.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS		c. COSATI Field/Group
Air Quality Assessments Gasoline Hydrocarbons Motor Vehicles Evaporation	Fuels Ozone Temperature Exhaust Emissions	Refueling Cost Analysis Indolene Inspection Maintenance National Ambient Air Quality Standards	Vapor Pressure	

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 340
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

Abstract

In-use motor vehicle evaporative hydrocarbon emissions greatly exceed their applicable EPA emission standards. The primary reason is that the volatility of commercial gasoline is substantially greater than that of the certification test fuel specified by EPA (i.e., vehicles are simply not designed to handle the fuel volatility they regularly experience).

The long-term solution is to equate the volatilities of commercial and certification test gasolines. This can be done at: 1) the current volatility of commercial gasoline, 2) that of certification test gasoline, or 3) at some point in between. However, in the short term, only the reduction of commercial gasoline volatility has a significant environmental benefit, since the effect of certification fuel modifications must await the turnover of the vehicle fleet. This study examines the technological feasibility, costs, emission reductions, air quality impacts and cost effectiveness of the various long-term and short-term solutions to this problem.

For Further Information

For further information on the technical contents of this study, please contact Amy Brochu, U.S. Environmental Protection Agency, 2565 Plymouth Road, Ann Arbor, MI 48105 (phone (313) 668-4270). All of the references used in this study (except those which are publicly available), as well as all Agency correspondence associated with the study, are contained in Public Docket A-85-21. This docket is located in the West Tower Lobby at EPA Headquarters, 401 M Street, S.W., Washington, D.C. 20460 (phone (202) 382-7548). The docket can be viewed between 8:00 a.m. and 4:00 p.m., Monday - Friday. A reasonable fee may be charged for copying.

Public Comments

Written comments on all aspects of the study are encouraged. Please send comments to: Central Docket Section (LE-131), U.S. Environmental Protection Agency, Attention: Docket A-85-21, 401 M Street, S.W., Washington, D.C. 20460.

Table of Contents

Chapter 1: Introduction

I. Background and Purpose 1-1
II. Structure of the Report 1-2

Chapter 2: Current In-Use Evaporative Emissions

I. Introduction 2-1
II. Ozone Violations and Seasonal Trends 2-1
III. Sources of Evaporative HC Emissions 2-16
IV. Factors That Can Impact Evaporative Emissions from Motor Vehicles 2-17
V. Results of In-Use Motor Vehicle Testing . . 2-45
VI. Summary of Evaporative Emissions Problem and Development of Possible Control Scenarios . 2-79
Appendix 2A: Effect of Ambient Temperature on Motor Vehicle Evaporative Emissions . . . 2-90
Appendix 2B: Breakdown of Motor Vehicle Evaporative Emission Factors into Their Components . . 2-111

Chapter 3: Vehicle-Oriented Excess Evaporative HC Control

I. Introduction 3-1
II. Technology 3-1
III. Costs 3-17
IV. Conclusions 3-22
Appendix 3A: Detailed Derivation of Evaporative ECS Component Costs 3-26

Chapter 4: Technological Feasibility and Cost of In-Use Volatility Control

I. Introduction 4-1
II. Refinery Control of Gasoline Volatility . . 4-1
III. The Bonner and Moore Study 4-4
IV. Effect of RVP Control on the Butane Market. . 4-21
V. Fuel Economy Credit 4-24
VI. Economic Credit from Evaporative HC Recovery/Prevention 4-38
VII. Overall Cost of In-Use Gasoline RVP Control . 4-40

Chapter 5: Environmental Impact

I. Introduction 5-1
II. Motor Vehicle Evaporative HC Emission Factors 5-1
III. Motor Vehicle Exhaust Emission Factors . . . 5-16
IV. Effect of RVP Control on Gasoline Storage and Distribution Losses 5-19
V. Hydrocarbon Emissions Inventory Analysis . . 5-23
VI. Ozone Air Quality Analysis 5-33
VII. Effect of RVP Control on Toxic Emissions . . 5-37

Chapter 6: Analysis of Alternatives

I. Introduction 6-1
II. Methodology 6-3
III. Results 6-14
Appendix 6-A: Development of I/M Credits for Evaporative Emission Control Systems 6-47
Appendix 6-B: Effects of Increased Canister Size on Operating Costs 6-63
Appendix 6-C: Development of Non-Summer Evaporative Emission Recovery Credits for Four-Month Analysis 6-66

CHAPTER 1

Introduction

I. Background and Purpose

Current violation of the ambient ozone standard is somewhat widespread in urban areas across the United States. The Clean Air Act requires all areas to be in attainment by December 31, 1987.* Therefore, additional reduction of hydrocarbon emissions has become a growing concern. Of late, increasing attention has been directed toward evaporative hydrocarbon (HC) emissions from gasoline-fueled motor vehicles.

Evaporative HC emissions from motor vehicles originate from two basic components of the vehicle's fuel system -- the fuel tank and the carburetor. Evaporative emissions from the fuel tank -- known as "diurnal" losses -- occur as the gasoline vapors expand in response to daily ambient temperature increases. The other type of vehicle evaporative emissions -- referred to as "hot-soak" losses -- occur just after the engine is turned off, when residual engine heat causes the evaporation of some of the fuel remaining in the carburetor bowl and fuel lines. In fuel-injected vehicles, some hot-soak losses also originate from the fuel tank as well, probably due to recirculation of gasoline that has been heated by the engine.

Currently, all gasoline-fueled vehicles and trucks are equipped with evaporative control systems designed to capture the majority of these diurnal and hot-soak losses. A typical system consists of a canister filled with carbon granules which adsorb the HC vapors generated in the fuel tank and the carburetor. Later, while the engine is operating, the evaporative canister is periodically purged with air and the collected HCs are stripped from the canister and burned in the engine.

Light-duty gasoline vehicles (LDGVs) and gasoline trucks weighing less than 6000 lbs. GVW (rated gross vehicle weight), classified as $LDGT_1$s, have been equipped with evaporative canisters since 1971, when the first evaporative HC standards came into effect. Evaporative control of heavier trucks came later, with canisters first installed in light-duty gasoline trucks over 6000 lbs. GVW ($LDGT_2$s) in 1979 and in heavy-duty gasoline vehicles (HDGVs) in the current model year (1985). Current evaporative HC standards for these classes -- required to be met during certification testing -- are as follows: 2.0 grams/test for LDGVs, $LDGT_1$s and $LDGT_2$s; 3.0 grams/test for HDGVs at 14,000 lbs. GVW or less; and 4.0 grams/test for HDGVs greater than 14,000 lbs. GVW. These standards represent the sum of diurnal and hot-soak losses measured via the Sealed Housing Emission Determination (SHED) test, as outlined in the Code of Federal Regulations (Part 86, Subparts B and M).

---

* 1982 was the original date by which attainment was to be achieved; however, under special circumstances, an extension to 1987 is permitted. The Act makes no provisions beyond 1987.

Evaporative control systems are designed to meet these HC standards when the vehicle is fueled with certification test gasoline (Indolene), which has a typical Reid Vapor Pressure (RVP) -- a measure of volatility -- of 9.0 psi. Although this level of volatility was representative of commercial fuels in the early 1970's when certification test fuel specifications were developed, the RVP of commercial gasoline has risen steadily since then due primarily to an increasing butane content in response to rising energy costs. Results of EPA's in-use emission factor testing indicate that evaporative emissions are significantly greater with fuels of higher volatility; therefore, evaporative emissions from vehicles operating on commercial fuels are well above the certification standards. Further, EPA's testing has also revealed that the majority of in-use carbureted vehicles are unable to meet the evaporative standards even while operating on Indolene (9.0 psi), which suggests possible design problems such as inadequate canister purge during typical operating conditions Fuel-injected vehicles (a small minority in today's fleet, but expected to dominate late 1980's sales) perform well on Indolene, but greatly exceed 2 grams/test on commercial fuel.

Based on these findings, EPA has concluded that the majority of vehicles being driven in the field today are exceeding the current evaporative HC standards and will continue to do so, though to a lesser extent, in the future. This evaporative excess is a significant contributor to the current ozone non-attainment problem. The purpose of this report is to analyze various strategies designed to reduce this evaporative excess via in-use fuel volatility controls and/or modifications to certification fuel volatility specifications and test procedure.

II. Structure of the Report

In addition to this Introductory Chapter, the report is divided into five major sections. The first (Chapter 2) discusses the current in-use situation and lays the groundwork for the rest of the study. Topics examined are: 1) the current ozone non-attainment problem and seasonal trends in violations,

2) the sources of evaporative HC emissions (both motor vehicle and stationary), 3) various factors affecting motor vehicle evaporative emissions (such as evaporative control system design, fuel volatility, use of alcohol blends, and ambient temperature conditions), 4) results of EPA's in-use vehicle testing (used to define the basic sources of the motor vehicle evaporative excess and also the effect of fuel volatility on exhaust emissions), and 5) the HC control strategies to be evaluated in the remainder of the study. Next, Chapters 3 and 4 evaluate the technical feasibility and cost of vehicle-related controls and in-use fuel volatility controls, respectively. Chapter 5 assesses the environmental impacts associated with each of the control strategies, in terms of projected HC emissions and ambient ozone concentrations; included in these estimates is the impact of in-use RVP control on gasoline storage and distribution losses (from bulk terminals, refueling, etc.). Finally, in Chapter 6, the various control strategies are analyzed and compared on the basis of emission reductions, costs, and cost-effectiveness. This final chapter also addresses the sensitivity of these estimates to various factors such as implementation of refueling loss controls (on-board or Stage II), development of an inspection/maintenance program for evaporative control systems, exclusion of exhaust emission benefits, and others.

CHAPTER 2

Current In-Use Evaporative Emissions

I. Introduction

This chapter provides the basic background information necessary to put this study of evaporative hydrocarbon (HC) control measures into the proper context. The first section following this introduction discusses the current widespread ozone non-attainment problem, which has prompted the further study of HC control strategies. Section III provides a brief background on the origin of evaporative HC emissions from motor vehicles and gasoline storage and distribution sources. As the focus of this study is motor vehicle losses, Section IV addresses various factors that can impact the level of these evaporative emissions. These factors include: 1) the motor vehicle evaporative control system design, 2) in-use fuel volatility (including the effect of weathering), 3) use of alcohol blends, and 4) ambient temperature conditions. Following this discussion, Section V explains how data from EPA's in-use emission factor test program have been used to determine the major reasons for excess evaporative emissions from motor vehicles in the field (i.e., improper design of the purge system, malmaintenance and defects, higher commercial fuel volatility, and evaporative system tampering). Test results are also used to estimate the effect of fuel volatility on exhaust emissions. Finally, Section VI summarizes the current problem and discusses possible measures to control the evaporative emissions excess, such as the reduction of in-use fuel volatility and/or revisions to certification fuel specifications and test procedure; the specific control options to be evaluated throughout the rest of this study are outlined here.

II. Ozone Violations and Seasonal Trends

Current violation of the National Ambient Air Quality Standard (NAAQS) for ozone is quite widespread, with 54* urban areas currently designated as "non-attainment" by EPA's Office of Air Quality Planning and Standards (OAQPS).[1] As projections presented later in Chapter 5 will show, this non-attainment problem is expected to continue without further control of HC emissions.

---

* Includes 7 California cities.

Examination of ozone monitoring data recorded at sites in the non-attainment areas has revealed seasonal trends in ozone violations. As might be expected, the majority of all ozone violations occur during the warmer months of the year, when ambient conditions are most favorable to ozone formation. These seasonal trends are important in determining during what period (i.e., specific months) hydrocarbon emission reductions would be most valuable. This is an important consideration with respect to any in-use fuel-related control measures, as they include the flexibility to be implemented throughout the year or during only specific months. However, other evaporative HC control measures such as revisions to certification fuel specifications and test procedure would affect vehicle design and, thus, represent year-round control.

The following paragraphs begin with a brief description of the method by which the 54 urban areas mentioned above were designated as "non-attainment." This is followed by a review of seasonal trends in ozone violations within the non-California areas.

All ozone monitoring data recorded in the Storage and Retrieval of Aerometric Data (SAROAD) system between 1981 and 1983 (inclusive) were examined for ozone violations. If the sites within a specific Standard Metropolitan Statistical Area (SMSA) had not recorded any daily maximum 1-hour ozone concentrations greater than the level of the NAAQS (0.125 ppm) in 1982 or 1983, then the SMSA was considered to be in compliance with the standard and was not examined further.[1] For each of the SMSAs that failed this initial test, the fourth highest daily maximum 1-hour concentration during the 3-year period was determined; if this value was less than the standard of 0.125 ppm, the city was dropped from consideration. With a further stipulation that the area have a population greater than 200,000,* 54 SMSAs were designated as current non-attainment areas to be modelled for ozone by EPA.[1] However, since California has already implemented its own gasoline volatility controls, only the 47 non-California cities were considered in this study. These 47 current ozone non-attainment cities, or SMSAs, are listed in Table 2-1, along with their respective "design values", or base-year ambient ozone concentrations to be used in EPA's modelling.[1]

---

* This population cutoff was determined as part of EPA's rural ozone policy, outlined in Reference 2.

Table 2-1

47 Current Non-California Ozone Non-Attainment Areas, With Design Values* (ppm)[1]

Region 1	
Boston Metropolitan Area	0.16
Greater Metropolitan Connecticut	0.14
Providence-Pawtucket-Warwick, RI-MA	0.14
Springfield-Chicopee-Holyoke, MA-CT	0.19
Worcester, MA	0.13
Region 2	
New York Metropolitan Area	0.23
Region 3	
Allentown-Bethlehem-Easton, PA-NJ	0.14
Baltimore, MD	0.15
Harrisburg, PA	0.13
Huntington-Ashland, WV-KY-OH	0.13
Norfolk-VA Beach-Portsmouth, VA	0.14
Philadelphia Metropolitan Area	0.18
Pittsburgh, PA	0.13
Richmond, VA	0.13
Scranton-Wilkes-Barre, PA	0.13
Washington, DC-MD-VA	0.16
Region 4	
Atlanta, GA	0.17
Birmingham, AL	0.16
Charlotte-Gastonia, NC	0.13
Chattanooga, TN-GA	0.14
Memphis, TN-AR-MS	0.15
Miami, FL	0.14
Region 5	
Akron, OH	0.14
Canton, OH	0.13
Chicago Metropolitan Area	0.20
Cincinnati, OH-KY-IN	0.13
Cleveland, OH	0.13
Dayton, OH	0.13
Detroit, MI	0.15
Indianapolis, IN	0.13
Louisville, KY-IN	0.16
Milwaukee Metropolitan Area	0.14
St. Louis, MO-IL	0.14
Toledo, OH-MI	0.13
Youngstown-Warren, OH	0.13

Table 2-1 (Cont'd)

Region 6	
Baton Rouge, LA	0.17
Dallas-Fort Worth, TX	0.15
El Paso, TX	0.14
Houston, TX	0.28
New Orleans, LA	0.17
San Antonio, TX	0.14
Tulsa, OK	0.15
Region 7	
Kansas City, MO-KS	0.13
Region 8	
Denver-Boulder, CO	0.15
Salt Lake City-Ogden, UT	0.15
Region 9	
Las Vegas, NV	0.14
Phoenix, AZ	0.16

---

* Each area's "design value" is the fourth highest daily maximum 1-hour ozone concentration recorded during a 3-year period -- in this case, 1981, 1982 and 1983.

In an effort to determine during what period HC control is most valuable, ozone data recorded at all monitoring sites within each of these 47 SMSAs were examined for seasonal trends in ozone episodes. Reports of daily maximum 1-hour concentrations at each monitor, recorded for each day of the year, were obtained for two calendar years -- 1983 because it was the most recent complete set of data available at the time of this analysis, and 1980 because it represents a recent year with a relatively high number of ozone violations.

Results of the seasonal analysis of 1983 and 1980 ozone monitoring data are presented, respectively, in Tables 2-2 and 2-3. Included in the tables, for each of the 47 SMSAs, are number of monitoring sites, number of monthly violations, and maximum monthly ozone concentration. The number of violations represents the total number of days in which a 1-hour average ozone concentration at any given site exceeded 0.125 ppm (the NAAQS); because violations in a particular SMSA are summed over all monitoring sites in the city, total monthly violations can exceed 31. The maximum ozone concentration shown in the tables is the highest 1-hour average concentration recorded at any site within an SMSA during the given month.

As indicated in the tables, ozone violations tend to occur in the warmer months when temperature conditions are most favorable for ozone formation. According to 1983 data (summarized in Table 2-2), 38 of the 47 non-attainment areas experienced all ozone violations during the summer months (i.e., May through September, inclusive); further, all but two of the cities recorded at least 80 percent of their violations in the summer. The two excepted cities experienced very few ozone episodes during 1983 -- Scranton recorded only three violations with one in April, and Miami's only reported violation in 1983 fell during April.

As shown in Table 2-3, non-summer ozone violations were slightly more prevalent in 1980 than in 1983. In 1980, 19 of the cities experienced at least one ozone episode outside of the May-September period, compared to only 9 cities during 1983. However, the vast majority of 1980 violations occurred during the summer, with 42 of the 47 cities recording over 80 percent of all exceedances between May and September (inclusive).

In both 1980 and 1983, Houston experienced a relatively large number of ozone violations, recording 193 and 217 annual exceedances (respectively) over its 13 monitoring sites. In

Table 2-2

Monthly Trends in Ozone Violations - 1983

City	No. of Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Region 1													
Boston	3												
Violations							7	3	5	2			
Max. ppm		.021	-	.037	.116	.092	.205	.133	.146	.149	.108	.030	.032
Metro Conn	10												
Violations					5		74	63	65	60	1		
Max. ppm		-	-	-	.181	.118	.294	.223	.224	.222	.129	-	-
Providence	4												
Violations							2	2	2	3			
Max. ppm		.038	.048	.051	.101	.073	.171	.137	.132	.150	.119	.056	.043
Springfield	3												
Violations					2		7	10	7	3			
Max. ppm		.015	.077	.035	.175	.097	.162	.255	.185	.145	.107	.042	.035
Worcester	1												
Violations							1		2	1			
Max. ppm		-	-	-	.103	.080	.132	.120	.145	.145	.100	-	-
Region 2													
New York	8												
Violations					1		30	20	25	13			
Max. ppm		.050	.067	.059	.138	.099	.209	.224	.160	.172	.113	.065	.038
Region 3													
Allentown	3												
Violations							9	4	2				
Max. ppm		.040	.054	.057	.112	.092	.173	.138	.143	.120	.103	.069	.041
Baltimore	12												
Violations							1		2				
Max. ppm		.035	.075	.053	.071	.111	.149	.117	.151	.110	.082	.045	.034
Harrisburg	3												
Violations							7						
Max. ppm		.039	.066	.054	.111	.108	.200	.123	.120	.109	.090	.056	.032
Huntington	1												
Violations							2	5	4	1			
Max. ppm		.039	.081	.075	.076	.088	.130	.138	.130	.150	.091	.054	.048

Table 2-2 (continued)

City	No. of Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Norfolk	1												
Violations								1	1				
Max. ppm		.041	.061	.072	.083	.092	.121	.130	.135	.119	.070	.064	.044
Philadelphia	12												
Violations			1			1	56	38	32	22	1		
Max. ppm		.039	.145	.073	.120	.134	.205	.182	.181	.162	.138	.065	.080
Pittsburgh	7												
Violations							4	5	3	1			
Max. ppm		.064	.066	.094	.091	.108	.133	.142	.175	.141	.088	.061	.038
Richmond	3												
Violations							3	1	3	2			
Max. ppm		.040	.065	.075	.085	.090	.150	.150	.130	.140	.100	.055	.045
Scranton	4												
Violations					1		2						
Max. ppm		.037	.052	.061	.127	.073	.135	.114	.107	.106	.086	.068	.040
Wash. D.C.	12												
Violations							30	28	15	15			
Max. ppm		.040	.077	.073	.092	.102	.176	.195	.249	.175	.092	.058	.034
Region 4													
Atlanta	2												
Violations							2	14	12				
Max. ppm		-	-	-	.080	.122	.133	.195	.155	.100	.108	.070	-
Birmingham	3												
Violations								2	10				
Max. ppm		.058	.069	.085	.093	.098	.093	.142	.171	.113	.112	.072	.047
Charlotte	3												
Violations						1	1	3	5				
Max. ppm		.047	.071	.076	.086	.130	.135	.155	.148	.117	.117	.066	.057
Chattanooga	2												
Violations									6				
Max. ppm		.058	.073	.090	.085	.090	.118	.095	.150	.108	.103	.063	.058
Memphis	3												
Violations								3	6				
Max. ppm		.045	.070	.090	.090	.080	.095	.150	.148	.120	.100	.050	-
Miami	3												
Violations					1								
Max. ppm		.070	.060	.115	.230	.095	.070	.065	.100	.055	.090	.085	.055

Table 2-2 (continued)

City	No. of Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Region 5													
Akron	4												
Violations							2	4	3				
Max. ppm		.035	.068	.095	.095	.085	.130	.130	.130	.105	.115	.048	.035
Canton	2												
Violations							1		1				
Max. ppm		.033	.052	.082	.075	.097	.125	.123	.125	.098	.080	.058	.037
Chicago	23												
Violations							19	33	9	5			
Max. ppm		.043	.089	.072	.084	.089	.188	.180	.155	.141	.096	.065	.092
Cincinnati	8												
Violations							2	4	20	1			
Max. ppm		.050	.073	.080	.080	.087	.135	.162	.190	.147	.095	.057	.042
Cleveland	6												
Violations							4	9	6	2			
Max. ppm		.040	.061	.075	.090	.085	.153	.158	.151	.135	.083	.083	.033
Dayton	4												
Violations									4				
Max. ppm		.035	.075	.077	.077	.075	.122	.120	.132	.105	.095	.047	.035
Detroit	3												
Violations							8	2	4	1			
Max. ppm		.044	.050	.087	.095	.116	.170	.136	.142	.125	.089	.038	.035
Indianapolis	6												
Violations							3	2	5				
Max. ppm		.044	.078	.076	.091	.094	.131	.138	.155	.104	.090	.065	.074
Louisville	3												
Violations							2	12	14				
Max. ppm		.042	.069	.071	.060	.075	.138	.148	.190	.116	.091	.060	.034
Milwaukee	9												
Violations							15	9	15	5			
Max. ppm		.030	.035	.047	.101	.090	.165	.179	.228	.140	.115	.037	.032
St. Louis	9												
Violations							10	15	34				
Max. ppm		.037	.066	.096	.107	.090	.160	.177	.243	.121	.104	.019	.036
Toledo	3												
Violations							3		1	1			
Max. ppm		.035	.040	.055	.070	.085	.130	.115	.125	.130	.100	.035	.030
Youngstown	1												
Violations							1						
Max. ppm		.040	.065	.080	.087	.080	.125	.100	.100	.097	--	.035	

Table 2-2 (continued)

City	No. of Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Region 6													
Baton Rouge	6												
Violations						1	1	1	3	2			
Max. ppm		.070	.061	.107	.090	.130	.130	.125	.169	.139	.120	.085	.100
Dallas	7												
Violations						6	5	6	23	3			
Max. ppm		.070	.080	.080	.090	.140	.170	.170	.170	.140	.120	.070	.050
El Paso	3												
Violations								2		1			
Max. ppm		.090	.090	.090	.080	.110	.100	.140	.120	.150	.100	.090	.090
Houston	13												
Violations			3	12	4	62	30	28	33	25	16	1	3
Max. ppm		.120	.140	.160	.140	.290	.230	.240	.250	.340	.190	.150	.180
New Orleans	4												
Violations													
Max. ppm		.066	.094	.113	.084	.124	.093	.115	.121	.117	.096	.064	.060
San Antonio	2												
Violations										2			
Max. ppm		.080	.090	.070	.070	.090	.110	.100	.120	.140	.120	.060	.060
Tulsa	3												
Violations								4	2				
Max. ppm		.052	.067	.070	.083	.091	.099	.138	.132	.112	.097	.057	.041
Region 7													
Kansas City	5												
Violations								1	2				
Max. ppm		.037	.080	.080	.079	.065	.095	.130	.142	.116	.093	.061	.046
Region 8													
Denver	7												
Violations					1		2	6	11	1			1
Max. ppm		.077	.064	.120	.141	.106	.155	.140	.176	.127	.075	.080	.128
Salt Lake City	6												
Violations						1		2	4				
Max. ppm		.046	.059	.079	.067	.130	.102	.135	.158	.113	.089	.051	.052
Region 9													
Las Vegas	3												
Violations										1			
Max. ppm		.098	.118	.086	.077	.091	.100	.110	.121	.138	.085	.074	.078
Phoenix	9												
Violations						2	1	2	8	1			
Max. ppm		.069	.078	.090	.085	.132	.135	.160	.160	.139	.104	.073	.050

Table 2-3

Monthly Trends in Ozone Violations - 1980

City	No. of Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Region 1													
Boston	10												
Violations							7	11	8				
Max. ppm		-	-	-	.093	.079	.154	.150	.159	.098	.061	.032	.029
Metro Conn.	10												
Violations						12	44	89	50	30			
Max. ppm		.043	.058	.060	.090	.189	.276	.303	.249	.230	.106	.034	.032
Providence	3												
Violations						1	6	9	8	1			
Max. ppm		.040	.050	.070	.100	.140	.190	.208	.222	.135	.112	.060	.052
Springfield	1												
Violations							2	5	1	1			
Max. ppm		-	-	-	-	-	.185	.153	.155	.150	.087	-	-
Worcester	3												
Violations							2	3	1				
Max. ppm		-	-	-	.075	.095	.177	.193	.170	.106	.080	-	-
Region 2													
New York	9												
Violations				1		3	13	49	26	5			
Max. ppm		.032	.036	.222	.095	.159	.190	.188	.174	.131	.077	.040	.092
Region 3													
Allentown	4												
Violations		1	1			2	3	4	4	7		2	
Max. ppm		.139	.344	.050	.090	.127	.161	.152	.143	.151	.083	.152	.044
Baltimore	16												
Violations					1	2	8	54	38	11			
Max. ppm		.039	.041	.057	.137	.128	.162	.183	.195	.157	.091	.061	.058
Harrisburg	2												
Violations									1	1			
Max. ppm		.078	.048	.078	.095	.115	.116	.112	.128	.128	.088	.068	.035
Huntington	1												
Violations					1	1		2					
Max. ppm		.037	.053	.056	.130	.129	.088	.147	.120	.090	.089	.070	.052

Table 2-3 (continued)

City	No. of Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Norfolk	2												
Violations								1					
Max. ppm		.031	.044	.050	.091	.115	.120	.126	.119	.116	.076	.061	.035
Philadelphia	17												
Violations						3	30	60	43	7		2	1
Max. ppm		.043	.050	.070	.110	.142	.197	.228	.201	.168	.089	.349	.239
Pittsburgh	12												
Violations							7	14	10	1			
Max. ppm		.039	.051	.063	.087	.117	.174	.298	.160	.128	.087	.076	.044
Richmond	3												
Violations						1		1					
Max. ppm		.030	.055	.055	.095	.135	.115	.130	.120	.120	.075	.055	.045
Scranton	4												
Violations							3	3	2	1			
Max. ppm		.034	.041	.054	.092	.120	.155	.148	.145	.151	.089	.041	.045
Wash. DC	15												
Violations						3	2	18	28	5			
Max. ppm		.040	.055	.055	.088	.147	.133	.195	.207	.167	.090	.071	.070
Region 4													
Atlanta	4												
Violations							1	4	4	2			
Max. ppm		.050	.090	.070	.100	.105	.135	.160	.150	.150	.080	.080	.070
Birmingham	3												
Violations								9	3				
Max. ppm		-	-	-	-	-	.117	.157	.161	.115	.099	.092	.072
Charlotte	4												
Violations								5	4				
Max. ppm		.045	.075	.071	.092	.117	.118	.154	.145	.119	.098	.077	.056
Chattanooga	2												
Violations							1						
Max. ppm		.045	.070	.060	.090	.100	.135	-	-	.095	.090	.068	.060
Memphis	4												
Violations					1	1	7	2		2			
Max. ppm		.053	.070	.070	.165	.130	.140	.200	.110	.160	.072	.087	.060
Miami	2												
Violations									1	1	1		
Max. ppm		.052	.100	.075	.070	.080	.050	.085	.155	.130	.150	.075	.070

Table 2-3 (continued)

City	No. of Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Region 5													
Akron	4												
Violations								1		1			
Max. ppm		.030	.040	.053	.088	.103	.103	.133	.118	.153	.073	.063	.040
Canton	2												
Violations													
Max. ppm		.035	.037	.070	-	.095	.100	.110	.105	.085	.080	.062	.040
Chicago	27												
Violations				4			4	17	9	1			
Max. ppm		.039	.056	.361	.111	.124	.148	.195	.163	.132	.074	.056	.091
Cincinnati	7												
Violations							16	22	7				
Max. ppm		.037	.050	.060	.102	.122	.165	.172	.137	.120	.100	.065	.050
Cleveland	7												
Violations								2					
Max. ppm		.038	.043	.060	.090	.104	.119	.152	.102	.099	.061	.061	.040
Dayton	4												
Violations								3	1				
Max. ppm		.040	.050	.055	.092	.115	.102	.156	.132	.100	.082	.052	.042
Detroit	8												
Violations					1	2	1	7	3				
Max. ppm		.040	.092	.083	.139	.145	.155	.149	.151	.121	.085	.082	.084
Indianapolis	5												
Violations							2	3					
Max. ppm		.107	.119	.073	.102	.123	.140	.142	.121	.117	.117	.056	.049
Louisville	8												
Violations						1	5	18	15	2	1		
Max. ppm		.045	.060	.060	.090	.175	.169	.190	.197	.158	.130	.081	.081
Milwaukee	8												
Violations							3		8	1			
Max. ppm		.033	.045	.045	.086	.119	.140	.124	.177	.126	.046	.035	.029
St. Louis	19												
Violations				1	3	2	13	29	18	6	5		1
Max. ppm		.070	.078	.205	.161	.199	.199	.171	.177	.162	.157	.105	.125
Toledo	2												
Violations								3	1				
Max. ppm		.035	.050	.060	.105	.105	.115	.140	.145	.105	.080	.050	.035
Youngstown	2												
Violations							1						
Max. ppm		.038	.037	.055	.085	.075	.160	.110	.095	.090	.060	.050	.050

Table 2-3 (continued)

City	No. of Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Region 6													
Baton Rouge	3												
Violations								4	1	4	3		
Max. ppm		.057	.056	.064	.085	.087	.124	.154	.137	.193	.218	.102	.070
Dallas	7												
Violations					1	2	7	5	3	2			
Max. ppm		.060	.110	.120	.130	.180	.180	.150	.140	.160	.100	.090	.100
El Paso	2												
Violations							2		1	3		1	
Max. ppm		.080	.090	.070	.080	.120	.160	.080	.130	.160	.100	.130	.090
Houston	13												
Violations		6	1	1	4	27	19	31	36	31	22	10	5
Max. ppm		.160	.190	.140	.150	.280	.220	.220	.260	.340	.350	.230	.160
New Orleans	1												
Violations								1					
Max. ppm		.031	.040	.032	.038	.023	.114	.126	.095	.068	.088	.072	.048
San Antonio	3												
Violations													
Max. ppm		.060	.100	.080	.110	.120	.120	.120	.110	.120	.120	.090	.070
Tulsa	3												
Violations							1	5	4	4			
Max. ppm		.066	.068	.098	.088	.117	.129	.201	.145	.132	.087	.077	.047
Region 7													
Kansas City	5												
Violations							1	9	5	1			
Max. ppm		.040	.060	.080	.120	.090	.135	.160	.160	.140	.108	.087	.051
Region 8													
Denver	8												
Violations								3	1				
Max. ppm		.086	.102	.068	.080	.116	.117	.165	.128	.103	.100	.072	.085
Salt Lake	5												
Violations							3	7	2	1			
Max. ppm		.061	.085	.092	.088	.121	.155	.182	.178	.146	.105	.075	.040
Region 9													
Las Vegas	3												
Violations		1	1									1	1
Max. ppm		.145	.135	.080	.113	.080	.090	.095	.093	.049	.118	.169	.143
Phoenix	8												
Violations							8	14	3	1	1		
Max. ppm		.049	.088	.095	. 08	.110	.148	.174	.143	.133	.129	.097	.078

1980, 25 percent of these violations occurred outside of the May-September period; the 1983 figure is slightly lower at 18 percent non-summer violations.

In evaluating various seasonal options for in-use fuel volatility control, it is important to consider the periods during which ozone reductions are most needed. The upper half of Table 2-4 summarizes the seasonal trends in ozone violations indicated in the previous two tables, outlining the percentage of total annual violations that occurred in the 47 areas during specific summer periods (i.e., various monthly combinations) in 1980 and 1983. These percentages are based on total violations summed over all monitors in all 47 areas; therefore, those cities with more monitors contribute more heavily to the weighted average. Because Houston recorded a relatively large number of non-summer violations, results are presented for all 47 cities combined and then for all cities excluding Houston.

As shown, the individual month during which the highest percentage of all 1980 violations occurred was July, with 39 percent of the total; in 1983, August was the highest with 31 percent of total annual violations. In addition to individual months, the 2-,3-,4-, and 5-month periods recording the highest percentages of total violations are presented. As shown, in-use fuel volatility control between May and September (inclusive) could potentially have an impact on 94-97 percent of all ozone violations in current non-attainment areas; if Houston were excluded, this 5-month period would encompass essentially all ozone episodes. Four-month control would impact just slightly less of the ozone season -- 89-92 percent of total violations in all cities and 94-98 percent if Houston were excluded.

The bottom half of Table 2-4 summarizes the seasonal trends in peak ozone concentrations, first showing the average of all 47 cities' peak ozone levels by month, then including only those concentrations over the NAAQS (0.125 ppm). The data used are those in Tables 2-2 and 2-3 for 1983 and 1980, respectively. As can be seen, average peak ozone concentrations show a definite trend between highs of 0.156 - 0.162 ppm in July or August to lows of 0.050 - 0.055 ppm in January. When only peaks above the standard are included, the trend is less pronounced. The reason for this is that the summer averages are a mixture of marginal and severe violations, while the winter averages primarily consist of the marginal to moderate violations of those cities with more severe violations in the summer. Cities with marginal violations in the summer generally show no violations in the winter and, thus, are excluded from the averaging.

Table 2-4

Seasonal Trends in Ozone Violations in 47 Non-Attainment Areas

Months	Percent of Total Annual Violations			
	All Cities		All Cities Except Houston*	
	1980	1983	1980	1983
April	1	1	1	1
May	5	5	3	1
June	13	22	14	23
July	39	26	43	28
August	27	31	28	34
September	10	13	9	13
October	2	1	1	0
Jul-Aug	66	57	71	62
Jun-Aug	79	79	85	85
Jun-Sep	89	92	94	98
May-Sep	94	97	97	99

Months	Average of City-Specific Monthly Peaks (ppm)			
	All Ozone Levels		Ozone Levels Above Standard (.125 ppm)	
	1980	1983	1980	1983
January	0.055	0.050	0.148	--
February	0.075	0.073	0.223	0.143
March	0.082	0.080	0.232	0.160
April	0.101	0.099	0.145	0.162
May	0.123	0.103	0.160	0.155
June	0.151	0.144	0.166	0.161
July	0.162	0.149	0.174	0.161
August	0.151	0.156	0.165	0.162
September	0.134	0.133	0.158	0.155
October	0.101	0.102	0.189	0.152
November	0.084	0.061	0.206	0.150
December	0.067	0.053	0.167	0.154

---

* Houston is excluded here due to a relatively large number of non-summer violations.

III. Sources of Evaporative HC Emissions

A. Motor Vehicles

Evaporative HC emissions from motor vehicles can be separated into two basic categories -- "diurnal" and "hot-soak" losses -- that result from different processes. Diurnal emissions consist of HCs both evaporated and displaced from the vehicle's fuel tank as the vehicle tracks the diurnal swing in ambient temperatures. Each day, as the fuel in the tank and the vapor above the fuel heat up, more of the liquid fuel evaporates and the vapor itself expands, with both phenomena causing HCs to be released into the atmosphere (unless captured by a control system). Fuel volatility, size of vapor space, initial ambient temperature, and magnitude of the diurnal temperature swing can all impact the level of evaporative emissions from a vehicle's fuel tank.

Hot-soak emissions occur during the period immediately following engine shut-down (i.e., at the end of each vehicle trip). These losses will occur both as distillation from the fuel metering system (either a carburetor or a fuel injector) and as evaporation from the fuel tank. Evaporative emissions from the fuel metering system occur as part of a different process than that described for diurnal losses. When the vehicle's engine is shut off, so is the cooling system. The engine block and surrounding area heat the engine coolant (which is no longer circulating) and other engine components, usually kept cool by the circulating coolant, before natural cooling begins to take effect. Any fuel remaining in the carburetor bowl, or leaking from a malfunctioning fuel injector, will undergo a distillation process during this time and vapors will be released to the atmosphere unless captured by a control device. This was previously considered the only source of hot-soak emissions, but there have been recent indications that the fuel tank in fuel-injected vehicles can undergo a temperature change during vehicle operation as a result of recirculation of fuel heated by the engine. Vapor production in the tank would be the same type as that described above for diurnal losses; however, because these tank losses are not in response to ambient temperature changes, they are classified as hot-soak emissions.

B. Gasoline Storage and Transfer

In addition to diurnal and hot-soak losses from motor vehicles, evaporative HC emissions are also released during gasoline storage and transfer. These stationary gasoline-related sources can be divided into three basic categories: 1) bulk storage and bulk transfer of gasoline, 2) service stations (Stage I), and 3) vehicle refueling (Stage II).

Storage emissions are very similar to diurnal losses from motor vehicles in that they occur as gasoline in a tank responds to daily increases in ambient temperature. The transfer losses (included in all three categories) result from the displacement of gasoline vapors within a previously closed tank with liquid fuel; as the liquid goes in the tank, the vapors escape through available openings (primarily the refueling line).

Gasoline storage and distribution losses are dependent upon such factors as fuel volatility, ambient temperature conditions, tank configurations, method of fill, etc. The three source categories will be discussed in more detail in Chapter 5, where the effect of fuel volatility on the magnitude of stationary source evaporative losses will be addressed.

IV. Factors That Can Impact Evaporative Emissions from Motor Vehicles

A. Evaporative Control System Design

1. Description

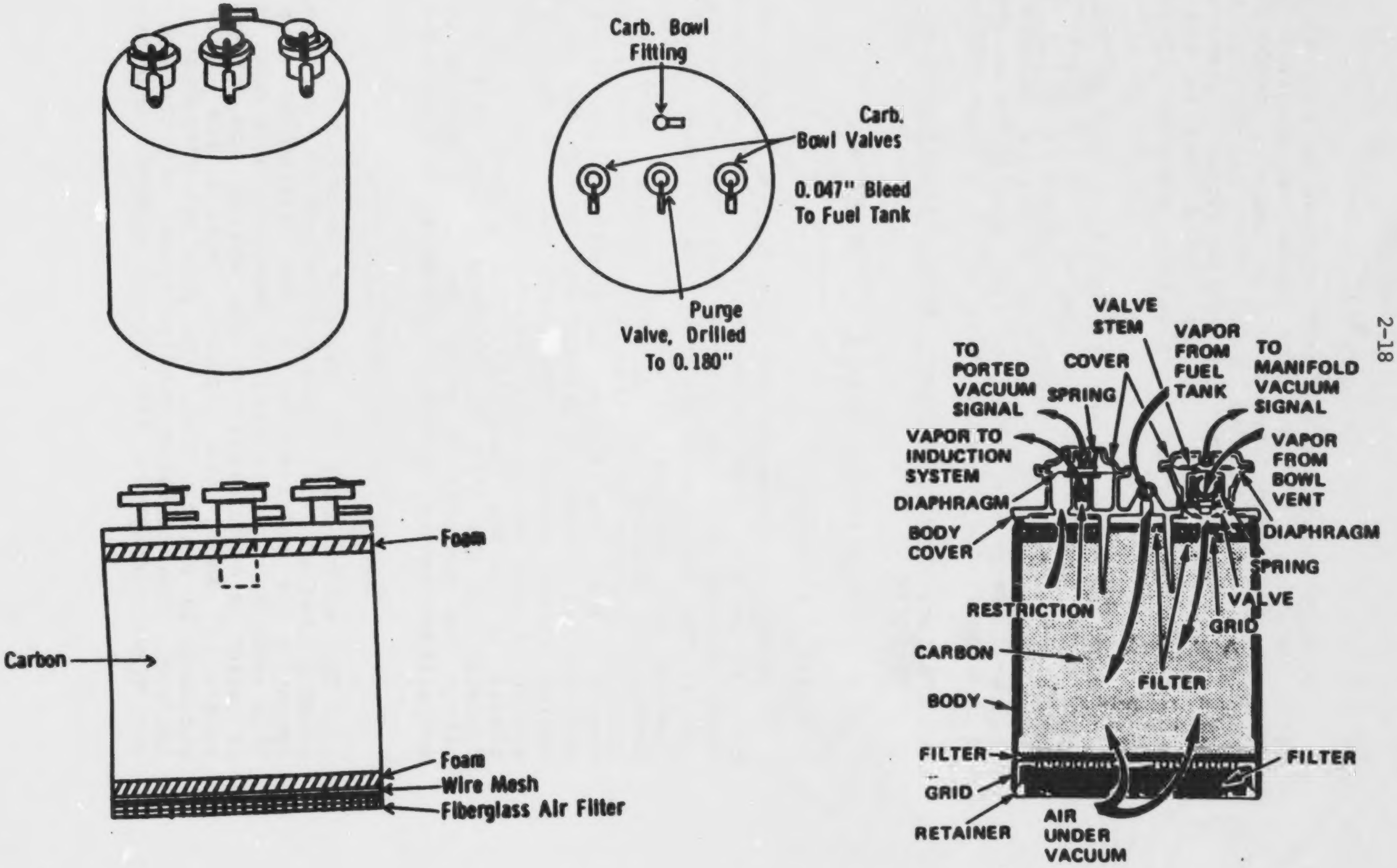
Present evaporative emission control systems are composed of: 1) an activated carbon canister that adsorbs hydrocarbon vapor emitted from the vehicle fuel tank and carburetor bowl, and 2) the associated plumbing and hardware that control the loading and purging of the canister. Additionally, some carbureted systems use an air cleaner with an integrated charcoal element to further adsorb bowl and intake manifold vapors. When the engine is running, this stored vapor is desorbed, or purged, by drawing air through the canister to the engine intake system. The purge rate is controlled by the source of the vacuum (air cleaner, carburetor (above throttle blade) or intake manifold), the pressure drop through the canister and the size of the controlling orifice (located in either the canister or purge port). A diagram of a typical evaporative control system is presented in Figure 2-1.

2. System Working Capacity

The actual mass of gasoline vapors that an evaporative control system will continually adsorb and desorb during operation is referred to as the "system working capacity". This working capacity will be dependent upon many factors, some of which are internal to the system and others that are external. Among the internal factors are: the volume of charcoal in the canister, the physical characteristics of the charcoal, the canister configuration, and the volume of purge air drawn through by the control system. Factors that also

Figure 2-1

Typical Evaporative Control System Canister


Carb. Bowl Fitting
Carb. Bowl Valves
0.047" Bleed To Fuel Tank
Purge Valve, Drilled To 0.180"
Foam
Carbon
Foam
Wire Mesh
Fiberglass Air Filter
VALVE STEM
TO PORTED VACUUM SIGNAL
COVER
VAPOR FROM FUEL TANK
TO MANIFOLD VACUUM SIGNAL
SPRING
VAPOR TO INDUCTION SYSTEM
VAPOR FROM BOWL VENT
DIAPHRAGM
BODY COVER
DIAPHRAGM
SPRING
VALVE
GRID
RESTRICTION
CARBON
FILTER
BODY
FILTER
FILTER
GRID
RETAINER
AIR UNDER VACUUM

play a role in determining system working capacity, but which are subject to little or no system control, include: the temperature and humidity of purge air and the vapor concentration of the evaporative emissions. This latter effect was noted in an EPA report comparing the ability of two different charcoals to adsorb and desorb HC vapors using fuels of varying volatility, and will be discussed further in Chapter 3.[3]

Manufacturers can design evaporative emission control systems to have a specific system working capacity by adjusting those factors that are subject to their control, with consideration given to the variations in the external factors mentioned previously. Current certification tests are performed using Indolene, which has an average Reid Vapor Pressure (RVP) of 9.0 psi; therefore, this is the volatility level at which current evaporative control systems are designed to meet the current evaporative HC standard of 2 grams/test. Actual in-use fuel, however, has an RVP closer to 11.5 psi during the summer months, representing higher levels of evaporative emissions than those encountered by the canister during the certification test. Thus, there exists a significant difference in the levels of emissions that current evaporative control systems are designed to capture and those that are encountered in actual operation.

B. Fuel Volatility

1. Proper Measure of Fuel Volatility

A number of different gasoline properties may be used to indicate gasoline volatility. Each year, in a document referred to as D-439, the American Society of Tests and Measurements (ASTM) publishes recommended limits for several gasoline volatility parameters, including Reid Vapor Pressure (RVP), distillation characteristics (such as the temperature at which a given percentage of gasoline is evaporated), and the temperature corresponding to a given gasoline vapor-to-liquid ratio (V/L). For every month of the year, each state is assigned a "volatility class" that represents ASTM's recommended limits on the volatility of gasoline sold in that state. The five gasoline volatility classes are designated as A, B, C, D, and E; corresponding volatility limits for these five classes are shown in Table 2-5. As indicated, Class A is the least volatile and Class E is the most volatile. It should be noted that these ASTM specifications are merely recommended levels and are not legally binding for gasoline refiners. A number of states have adopted ASTM standards as legal limits. However, the effectiveness of these limits depends directly on enforcement and it is questionable how strictly these limits are enforced in many states (California being an exception).

Table 2-5

ASTM D-439 Gasoline Volatility Specifications

		Distillation Temp. (°F) at Given Percent Evaporated			
ASTM Volatility Class	Max. RVP (psi)	Max. @ 10% (T_{10})	Min. @ 50% (T_{50})	Max. @ 50% (T_{50})	Min. Temp. @ V/L = 20 ($T_{20V/L}$, °F)
A	9.0	158	170	250	140
B	10.0	149	170	245	133
C	11.5	140	170	240	124
D	13.5	131	170	235	116
E	15.0	122	170	230	105

Measured in-use RVP levels (grouped according to ASTM volatility class) and the effect of state limitations are addressed in more detail in Section 2 below.

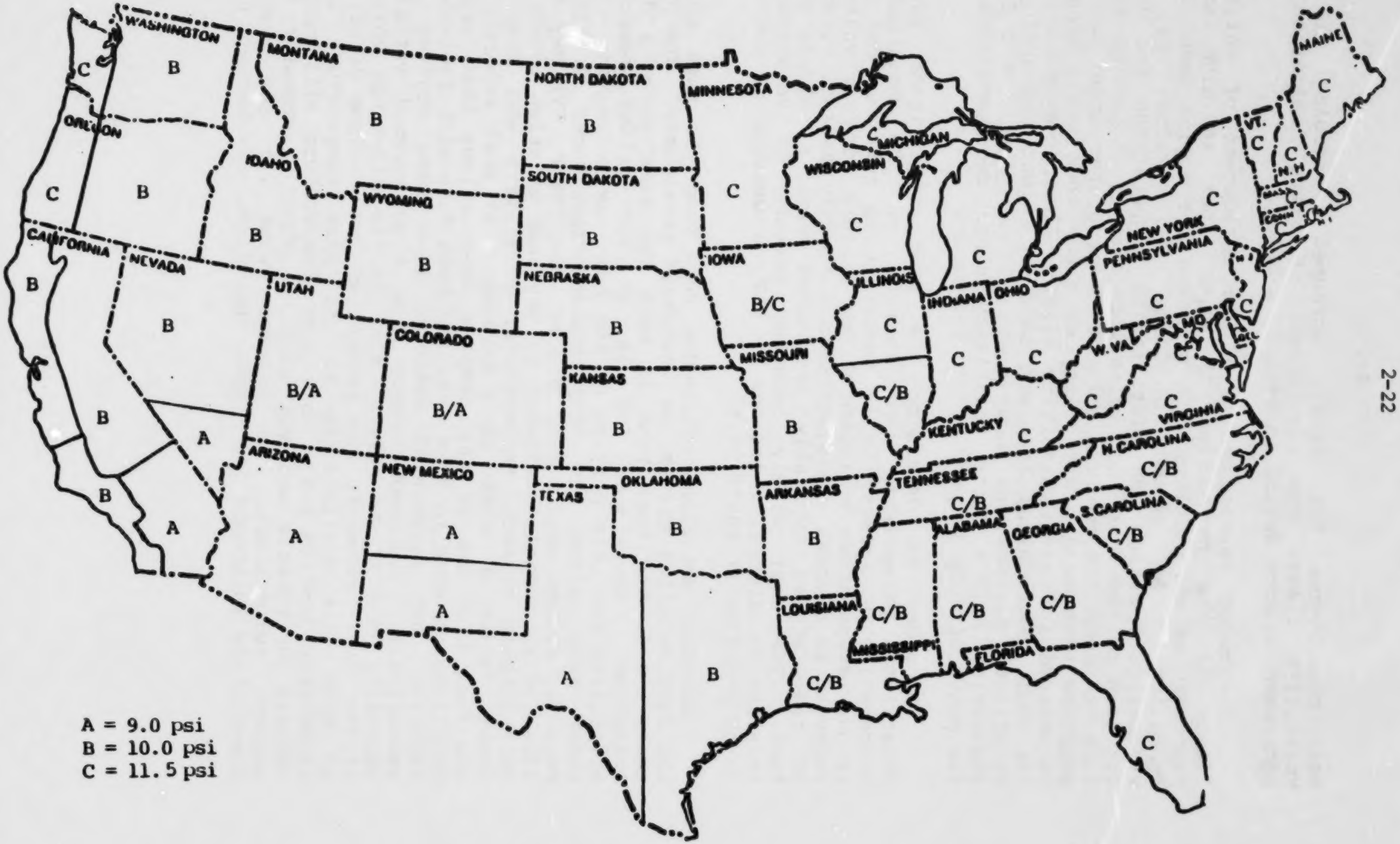
The major reason behind ASTM's assignment of volatility limits is the prevention of vapor lock at high ambient temperatures and problems with starting the engine under colder conditions. As shown in Table 2-5, values for RVP, vapor-liquid ratio, and distillation temperatures are defined for each of the five fuel volatility classes (A through E). In turn, minimum and maximum ambient temperatures under which no problems with cold startability or vapor lock would occur are calculated for each volatility class. Then, temperature data for each geographical area are used to select the appropriate volatility classes for each month of the year. A U.S. map indicating ASTM's state volatility class recommendations for the month of July is provided in Figure 2-2.

In order to determine the most significant gasoline volatility parameters with respect to the magnitude of evaporative HC losses, it is important to consider the source of the evaporative emissions. The measure of fuel volatility relevant to diurnal emissions should ideally reflect volatility at temperatures typically associated with a vehicle's fuel tank. The most widely accepted measure of volatility in relation to diurnal emissions is RVP, a measure of the fuel's vapor pressure at 100°F.[4,5]

Hot-soak emissions originate both from the fuel tank and the fuel metering system, as indicated previously. The process occurring in the fuel tank is much the same as with diurnal emissions. Therefore, RVP is an appropriate measure of volatility for this portion of the hot-soak emissions. On the other hand, since the temperatures experienced in the fuel metering system can be much higher than 100°F, RVP may not be ideal as an overall indicator of hot-soak emission levels. The relationship between temperature, volatility and evaporative losses is not as clear in a carburetor or fuel injector as in the fuel tank due to the complex interactions that occur.[6] Only limited work in this area has been done with fuel-injected vehicles, but carbureted vehicles have been studied fairly extensively. Hot-soak losses from a carbureted vehicle are generally felt to be related also to the mid-range volatility of the fuel, given as the percent of fuel volume distilled in an ASTM D216 distillation at the peak temperature in the carburetor bowl.[4,6-9] This peak temperature will vary from vehicle to vehicle and may also be affected somewhat by the ambient temperature. An average value for the peak bowl temperature is around 160°F and, therefore, the percent of fuel

Figure 2-2

ASTM's July Volatility Classes


WASHINGTON
C
B
OREGON
C
B
CALIFORNIA
B
B
B
A
NEVADA
B
A
IDAHO
B
MONTANA
B
WYOMING
B
UTAH
B/A
COLORADO
B/A
ARIZONA
A
NEW MEXICO
A
A
NORTH DAKOTA
B
SOUTH DAKOTA
B
NEBRASKA
B
KANSAS
B
OKLAHOMA
B
TEXAS
A
B
MINNESOTA
C
IOWA
B/C
MISSOURI
B
ARKANSAS
B
LOUISIANA
C/B
WISCONSIN
C
MICHIGAN
C
C
ILLINOIS
C
C/B
INDIANA
C
OHIO
C
KENTUCKY
C
TENNESSEE
C/B
MISSISSIPPI
C/B
ALABAMA
C/B
GEORGIA
C/B
FLORIDA
C
S.CAROLINA
C/B
N.CAROLINA
C/B
VIRGINIA
C
W.VA
C
MD
C
DEL
PENNSYLVANIA
C
NEW YORK
C
VT.
C
N.H.
C
MAINE
C
MASS
CONN
C
A = 9.0 psi
B = 10.0 psi
C = 11.5 psi

evaporated at 160°F ($\%_{160}$), in addition to RVP, may be a relevant fuel parameter for estimating hot-soak losses.[4,7] EPA is currently testing several fuels with the same RVP but with varying $\%_{160}$ points; hot-soak and diurnal losses are being measured for a total of 40 carbureted and fuel-injected vehicles to determine the impact, if any, of $\%_{160}$. As only very preliminary data are available at this time, no conclusions can be made.

Theoretically, because total evaporative HC emissions are represented by the sum of hot-soak and diurnal losses, the ideal measure of fuel volatility to be used in evaluating various evaporative emission control strategies would most likely be some combination of both RVP and $\%_{160}$. The weighting given each of these factors would be expected to vary with vehicle type, as fuel-injected vehicles have significantly lower hot-soak emissions and, thus, their relative losses would be more dependent upon RVP. Also, operating temperatures can vary from model to model, so 160°F may not be the appropriate point on the distillation curve for all vehicles.

Some attempts have been made to incorporate both RVP and various distillation points into a volatility index. In an effort to correlate evaporative emissions to the volatility of gasolines and methanol/gasoline blends, DuPont developed the Evaporative Index (EI), as shown below:

$$EI = 0.85(RVP) + 0.14(\%_{200}) - 0.32(\%_{100}).$$ [10]

In their application for a waiver of methanol blends, DuPont showed a correlation of EI versus evaporative emissions with an R^2 value of 0.86.[10] However, some criticisms have been raised with respect to DuPont's analysis, such as their combining the results of two independent testing programs without normalizing the results and the lack of higher volatility gasolines and blends in the analysis.[11,12]

The Front End Volatility Index (FEVI), which was developed for purposes other than emissions estimation (primarily the control of vapor lock), is defined as:

$$FEVI = RVP + 0.13(\%_{158}).$$ [13]

This index essentially includes the two terms most relevant to evaporative emissions ($\%_{158}$ is very close to $\%_{160}$). However, it is currently unknown if its relative weighting of the two parameters is appropriate.

Another gasoline property used to measure volatility is the temperature corresponding to a specified gasoline vapor-to-liquid ratio (V/L) at atmospheric pressure. This V/L is the volume of vapor formed at atmospheric pressure and test temperature divided by the initial volume of liquid gasoline tested. The temperature at which this vapor-to-liquid ratio is equal to 20 at atmospheric pressure is designated $T_{20V/L}$. The $T_{20V/L}$ parameter is included in the ASTM volatility specifications (shown in Table 2-5) and, according to API, is commonly used for blending purposes by refiners. Since limiting $T_{20V/L}$ can affect the other evaporative-related fuel parameters, it deserves further discussion here.

ASTM D-439 provides an empirical equation defining $T_{20V/L}$ as a function of the following parameters: RVP, the temperature at which 10 percent of the gasoline is evaporated (T_{10}), and the temperature at which 50 percent of the gasoline is evaporated (T_{50}). This equation is:

$$T_{20V/L} = 114.6 - 4.1(RVP) + 0.2(T_{10}) + 0.17(T_{50}).[14]$$

In the above equation for $T_{20V/L}$, RVP contributes significantly more to $T_{20V/L}$ than does T_{10} or T_{50}. According to survey data, fuels with RVPs ranging from 11.5 to 9.5 psi have T_{10}s ranging from 108-120°F and T_{50}s ranging from 210-220°F.[15] This 2-psi RVP range accounts for roughly an 8°F change in $T_{20V/L}$, if T_{10} and T_{50} are held constant. If the corresponding T_{10}s and T_{50}s for the different RVPs are used in the $T_{20V/L}$ equation, then the $T_{20V/L}$ changes by nearly 12°F. This indicates that RVP is the major factor affecting $T_{20V/L}$, but T_{10} and T_{50} are not negligible.

As mentioned earlier, EI and FEVI are indices relating RVP and distillation curve characteristics to gasoline volatility. The two are compared to $T_{20V/L}$ in the following paragraphs.

EI is similar to $T_{20V/L}$ in that both equations use RVP and two points on the distillation curve -- one near 100°F (T_{10}) and the other near 200°F (T_{50}). The equation estimating $T_{20V/L}$ is more readily understandable than that for EI, because the positive or negative signs of the coefficients reflect the trend in basic gasoline volatility changes with the specific parameters of the equation. For instance, as RVP increases, volatility increases and $T_{20V/L}$ decreases; also, as T_{10} decreases, volatility increases and $T_{20V/L}$ decreases. This is not the case for EI (where a high EI indicates high volatility) because as $\%_{100}$ increases, volatility should increase, yet EI decreases. Nevertheless, of all the terms in the equations, RVP has the most significant impact on both EI and $T_{20V/L}$. In each case, for a 2-psi change in RVP (11 psi to 9 psi) and corresponding distillation characteristics, the change in RVP accounts for 70-80 percent of the net change in the indices.

According to industry, FEVI and $T_{20V/L}$ are closely related and serve the same function in indicating gasoline volatility. Examination of the fuel properties reported in MVMA's summer gasoline surveys for 1977 through 1984 indicates an excellent correlation between FEVI and $T_{20V/L}$ (as calculated from ASTM's emperical equation). The R^2 correlation factor for $T_{20V/L}$ vs. FEVI ranged from 0.90 to 0.99 when MVMA's fuel samples were broken down by year and by volatility class. Theoretically, because of this close correlation and the fact that FEVI is dependent on only RVP and $\%_{158}$, controlling these two parameters should closely control $T_{20V/L}$. Again, RVP is the more significant of the two parameters, accounting for over 70 percent of the change in FEVI for a 2-psi change in RVP (from 11.5 psi to 9.5 psi).

From the above discussion, it appears that RVP and $\%_{160}$ are the most relevant of the available fuel parameters to indicate evaporative emission potential. The other parameters, EI, FEVI and $T_{20V/L}$ all essentially combine RVP with higher-temperature volatility indicators, but it is not clear that any of the three particular combinations adequately represent the overall evaporative emission potential for motor vehicles. It appears safer to address the two parameters separately at this point. However, as indicated above, little is currently known of the effect of $\%_{160}$ on evaporative emissions. Thus, this evaporative study will focus primarily on RVP as the most relevant measure of fuel volatility until such time as sufficient data are available to conduct a similar analysis of $\%_{160}$.

This limitation should not be of major concern since: 1) RVP is the dominant factor in both FEVI and EI, which have been used in the past to indicate overall evaporative emission potential, and 2) the vast majority of post-1990 vehicles are expected to be fuel-injected, which means that an even larger portion of their hot-soak (and total) evaporative losses will originate in the fuel tank -- where RVP is the most appropriate parameter -- than occurred with the carbureted vehicles used in the EI and FEVI studies.

2. Historical and Future Trends in Gasoline Volatility

Over the past decade, the volatility of commercial gasoline has gradually, but steadily, been increasing. This section reviews regional and nationwide RVP trends over time, along with a state-by-state comparison of violations of the fuel volatility limits suggested by ASTM versus the actual fuel inspection laws, if any, enforced by the State governments. Trends in gasoline volatility measures other than RVP are also reviewed here. Summer gasoline volatility is the focus because, as concluded in Section II of this chapter, in-use fuel control only during the summer months could have an impact on the majority of ozone violations.

Trends in commercial gasoline volatility were traced using results of two separate fuel surveys prepared each summer by the National Institute for Petroleum and Energy Research (NIPER) and the Motor Vehicle Manufacturers Association (MVMA).[16,15] Table 2-6 presents RVP trends for the 15 non-California regions included in the NIPER survey. As shown, overall non-California averages indicate a 9-percent increase in summer unleaded fuel RVP levels over the past 10 years. Increases within individual regions vary between 6 and 19 percent, with the greatest summer increase occurring in northern Illinois (sample area is Chicago).

To examine volatility trends over the past twenty years, it is necessary to look at leaded fuel which, of course, has been in use longer than unleaded fuel. National-average results of NIPER leaded gasoline surveys are presented graphically in Figure 2-3.[16] As shown in the top graph, the most significant summer RVP "boosts" occurred first in the 1972-74 period, and then again in 1981. Prior to 1972, summer fuel RVP levels were well within the range specified in the Code of Federal Regulations (CFR) for certification test fuels (8.7 to 9.2 psi); however, by the time the SHED* test began with the 1978 model year, the certification fuel RVP had been exceeded by the in-use fuel national average (approximately 9.6 psi). Since then, the CFR specifications have become even less representative of commercial fuel volatility, based on a 1984 summer leaded fuel average RVP of 10.3 psi for the nation (shown in the figure). Curves for T_{90}, T_{50}, and T_{10} (also presented in Figure 2-3) support the trend in increasing gasoline volatility, as well.

Results of the other fuel survey mentioned -- conducted by MVMA[15] -- are presented in Table 2-7. Here, instead of segregating by geographic region, average volatility characteristics for unleaded regular gasoline are shown for ASTM classes A, B, and C (as defined in Table 2-5). According to these survey results, the average RVP in Class C areas has increased by almost 10 percent over the past seven years to a level approaching 11.0 psi. Trends in other volatility parameters such as T_{10}, T_{50}, $\%_{158}$, and $T_{20V/L}$ (all

---

* Sealed Housing Evaporative Determination, which is the current test procedure.

Table 2-6

NIPER Survey Results[16]: Summer Gasoline RVP Trends by Region*

Region	Years											% Increase over Decade
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	
Northeast	9.8	10.0	10.2	10.7	10.5	10.5	10.8	10.8	10.9	10.5	10.7	9
Mid-Atlantic Coast	9.3	10.1	10.1	10.4	10.1	10.2	10.3	10.6	10.8	10.7	10.8	16
Southeast	9.6	9.6	9.7	9.5	9.4	9.6	9.8	9.9	10.1	10.3	10.2	6
Appalachian	10.5	10.6	10.5	10.4	10.1	10.6	10.5	10.9	11.1	11.4	11.1	6
Michigan	10.5	10.4	10.6	11.0	11.2	10.9	11.3	10.9	11.2	11.6	11.5	10
Northern Illinois	9.5	10.5	10.3	11.0	10.8	10.9	10.9	11.1	10.8	11.7	11.3	19
Central Mississippi	10.1	10.1	9.9	9.9	10.1	10.4	10.3	9.7	10.5	11.0	10.9	8
Lower Mississippi	9.4	9.6	9.6	9.5	9.8	9.5	9.7	9.3	10.1	10.1	10.0	6
Northern Plains	--	9.6	9.9	--	--	9.2	9.8	--	11.0	11.0	10.5	9
Central Plains	--	9.1	9.2	9.0	8.8	9.2	9.2	--	10.2	10.0	10.0	10
Southern Plains	9.2	9.3	9.2	9.3	9.1	9.5	9.2	9.7	10.0	9.8	9.8	7
Southern Texas	9.1	9.5	9.4	9.6	9.5	9.4	9.2	9.4	10.3	10.2	10.3	13
Southern Mountain	8.4	8.9	8.7	8.8	8.9	8.7	8.9	8.4	8.8	9.1	8.9	6
Northern Mountain	8.9	10.1	9.5	9.9	9.9	9.6	9.5	9.2	10.4	10.4	9.7	9
Pacific Northwest	9.5	9.9	10.6	10.4	10.0	10.3	10.8	11.0	10.8	11.2	10.8	14
National Average** (excluding California)	9.5	9.8	9.8	10.0	9.9	9.2	10.0	10.1	10.5	10.6	10.4	9

---

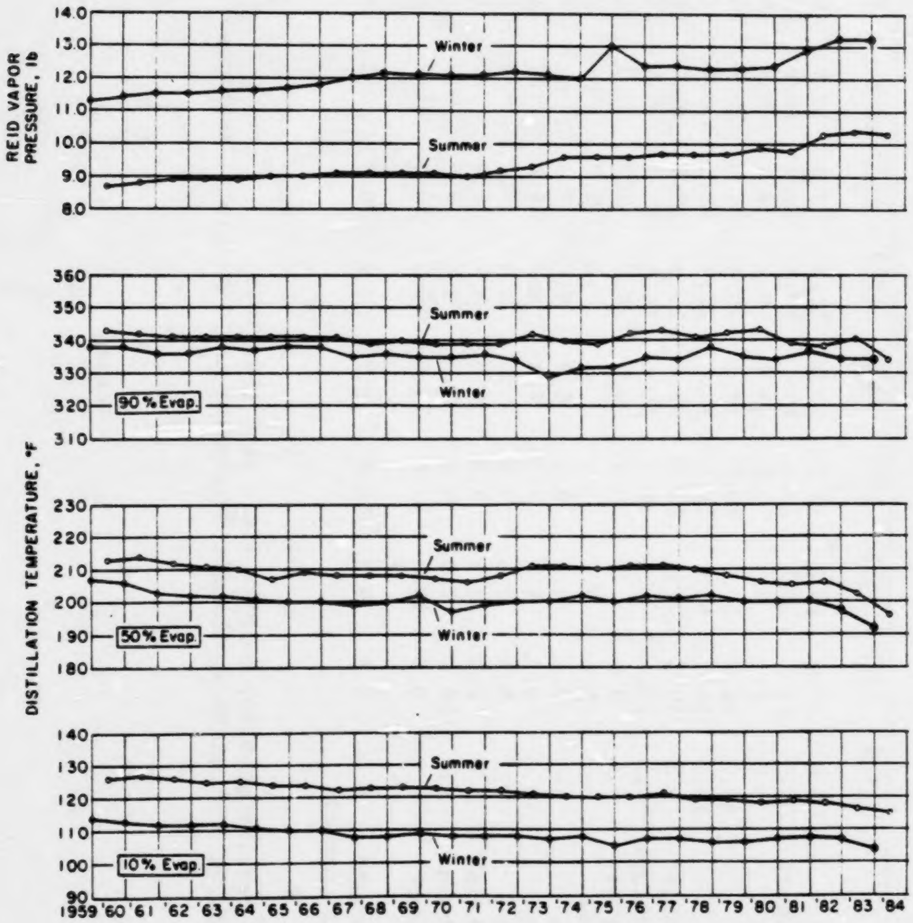
* Unleaded regular gasoline only (R + M/2 less than 90).

** Calculated as a straight arithmetic average of the 15 regional averages listed.

Figure 2-3

Volatility Trends in Leaded Gasoline

(NIPER Survey Results)[16]



- Trends of certain characteristics of leaded (regular) grade gasoline through summer 1980; leaded antiknock (R+M)/2 below 93.0 grade gasoline beginning winter 1980-81.

Table 2-7

MVMA Survey Results[15]:
Summer Gasoline Trends by ASTM Volatility Class*

Year	Volatility Class	No. of Gasolines Sampled	Avg. RVP (psi)	% of Sample Above ASTM RVP Max.	Avg. T_{10} (°F)	Avg. T_{50} (°F)	Avg. $\%_{158}$ (%)	Avg. $T_{20V/L}$ (°F)	% of Sample Below ASTM Minimum $T_{20V/L}$
1977	A	37	8.53	27.0	131.6	225.9	21.5	144.3	24.3
	B	66	8.72	0.0	128.0	218.3	23.4	141.6	4.6
	C	121	9.94	0.0	121.9	220.9	25.5	135.8	0.0
1978	A	38	8.25	13.2	129.0	222.9	22.5	144.5	23.7
	B	68	8.56	0.0	127.8	219.8	23.2	142.4	4.4
	C	123	9.67	0.8	120.8	220.0	25.8	136.5	0.0
1979	A	37	9.79	64.9	124.4	223.7	24.0	137.4	62.2
	B	67	10.10	55.2	123.6	219.4	25.0	135.2	47.8
	C	120	11.33	37.5	115.2	221.4	28.0	128.8	22.5
1980	A	39	8.27	20.5	123.8	222.5	23.4	143.3	28.1
	B	66	8.71	0.0	120.9	217.9	25.6	140.1	4.6
	C	124	9.88	1.6	113.0	218.5	28.4	133.8	0.8
1981	A	41	8.65	22.0	122.4	219.1	25.8	140.9	26.8
	B	66	9.30	6.1	122.0	218.1	25.9	137.9	10.6
	C	126	10.46	1.6	114.6	215.6	29.3	131.3	4.0
1982	A	37	9.16	37.8	123.8	220.0	25.2	139.2	43.2
	B	65	9.79	33.8	122.5	218.4	26.0	136.1	30.8
	C	125	11.06	28.8	114.0	215.6	29.6	128.7	11.2
1983	A	39	9.06	33.3	122.4	220.2	25.4	139.4	46.2
	B	64	9.65	31.2	120.1	216.6	26.5	135.9	29.7
	C	128	10.84	15.6	113.2	214.7	29.6	129.3	10.9
1984	A	39	8.80	28.2	118.7	210.9	28.5	138.1	51.3
	B	60	9.54	28.3	117.5	210.7	28.7	134.8	43.3
	C	125	10.89	22.4	108.8	206.7	32.7	126.8	30.4

---

* Unleaded regular gasoline only (R + M/2 less than 90).

defined in the previous section) are also shown in Table 2-7. These trends also indicate increasing fuel volatility over the past few years (i.e., lower T_{10}, T_{50}, and $T_{20V/L}$, and higher $\%_{158}$). It is important to note that $\%_{158}$ -- close to the $\%_{160}$ parameter associated with hot-soak emissions in the previous section -- has increased significantly by 28 percent (from 25.5 percent to a current average level of 32.7 percent) in Class C areas.

Pool average gasoline volatility properties for Class C gasolines are similar to those of unleaded regular gasoline described above. From 1977 to 1984, pool average RVP and $\%_{158}$, as determined from MVMA survey data (unleaded regular, unleaded premium, and leaded regular gasolines weighted 65 percent, 18 percent, and 17 percent, respectively) have both increased significantly. RVP has increased from 9.94 to 10.89 psi, and $\%_{158}$ increased from 26.6 to 32.6 percent.

Alcohol blends have, as a whole, higher volatility than do alcohol-free gasolines. The MVMA survey data reviewed above for alcohol-free gasoline volatility properties did not contain data on methanol blends, but did have volatility properties for ethanol blends.[15] Average RVP for eight 1984 gasoline samples containing an average of 9.4 percent ethanol was 12.3 psi. Average $\%_{158}$ was 44.6 percent. These levels are very similar to those of twelve 1983 gasoline samples also containing an average of 9.4 percent ethanol. Average RVP from these 1983 gasoline samples was 12.3 psi, and average $\%_{158}$ was 42 percent. Over these two years, $\%_{158}$ ranged from 30 to 55 percent while RVP ranged from 12 to 13.3 psi. These data indicate that Class C ethanol blends are significantly more volatile than Class C alcohol-free gasolines.

According to some theories, the increase in fuel volatility seen in alcohol-free gasoline is linked to the lead phasedown in gasoline over the past decade. Because of the reduction and/or elimination of the traditional octane-booster -- lead -- refiners must process heavier crudes in order to obtain the clear, high-octane fractions. As more crude undergoes hydro-cracking, more butane is produced; because butane enhances octane, and because the supply is in excess, it is allowed to remain a component of the gasoline. Unfortunately, butane is also a major volatility enhancer and its abundance is most likely the major reason for the increase in RVP over time.

As mentioned earlier, ASTM's volatility specifications are not enforceable by law, but are merely levels agreed upon by members of the refining industry. However, some states have adopted ASTM's RVP limits as part of their own gasoline inspection laws, which are enforceable.

Among the states which have adopted fuel volatility controls, the assigned RVP limits vary from month-to-month (as they do in the ASTM specifications) according to temperature conditions.* For the purposes of comparison to ASTM's D-439 limits, July was focused on, as this summer month is characteristic of high ozone violations (as mentioned in Section II of this chapter).

A comparison of state laws versus ASTM limits on RVP for the summer months is presented in Table 2-8. As shown, 21 of the states do not currently have inspection laws governing the RVP of gasoline sold within their boundaries.** Sixteen states have simply adopted ASTM's current year-round D-439 limits as law; in addition to these, four more states have RVP limits that correspond to ASTM's specifications at least during July. Among those state laws that differ from ASTM's D-439, there is a month-to-month variation involved in the comparison; for example, Alabama is more restrictive than ASTM in June and July, but less restrictive in August and September. However, as July is the focus here, the comparison is simplified. During this month, three states are more restrictive than ASTM and six are less restrictive (as indicated in Table 2-8).

In an effort to determine the effectiveness of ASTM's recommendations and State laws, fuel survey data were compared to these standards. Part of this comparison was shown previously in Table 2-7. As indicated there, over 22 percent of the Class C fuels sampled by MVMA in 1984 exceeded ASTM's maximum RVP specification of 11.5 psi; of these same samples, over 30 percent were below ASTM's recommended minimum level for $T_{20V/L}$.[15]

In Table 2-9, this comparison is put on a state-by-state basis. Here, the states are divided between those that have implemented gasoline RVP standards and those that have not. In turn, post-1982 NIPER summer survey results for these states were compared to both ASTM and State RVP standards for the month of July. As shown, 11 states have average RVPs above their respective ASTM specifications; 10 of these states have their own RVP standards and the other one does not. Further, of the 28 states having their own RVP limits (Hawaii excluded), roughly one-third of them had average summer RVPs above these State standards. Therefore, enforcement appears to be somewhat ineffective.

---

* The only exceptions to this are Louisiana, Wyoming, and Hawaii, which hold RVP constant throughout the year at 13.5, 13.0, and 11.5 psi, respectively.

** Washington, D.C. is included as one of the 24 states.

Table 2-8

Comparison of Summer RVP control: State Laws versus ASTM Limits*

States Same as ASTM**	States More Restrictive than ASTM	States Less Restrictive than ASTM	States With No RVP Specifications
Arizona (A)	Alabama (C/B)	Indiana (C)	Alaska (D)
Arkansas (B)	Mississippi (C/B)	Louisiana (C/B)	Connecticut (C)
Colorado (B/A)	No. Carolina (C/B)	Maryland (C)	Wash., D.C. (C)
Delaware (C)		Montana (B)	Kansas (B)
Florida (C)		So. Dakota (B)	Kentucky (C)
Georgia (C/B)		Wyoming (B)	Maine (C)
Hawaii (C)			Massachusetts (C)
Idaho (B)			Michigan (C)
Illinois (C,C/B)			Minnesota (C)
Iowa (B/C)			Nevada (A,B)
Missouri (B)			New Hampshire (C)
Nebraska (B)			New Jersey (C)
New Mexico (A)			New York (C)
No. Dakota (B)			Ohio (C)
Rhode Island (C)			Oklahoma (C)
So. Carolina (C/B)			Oregon (B,C)
Tennessee (C/B)			Pennsylvania (C)
Utah (B/A)			Texas (A,B)
Virginia (C)			Vermont (C)
Wisconsin (C)			Washington (B,C)
			West Virginia (C)

---

* Summer month examined is July; California is excluded from the comparison.

** ASTM volatility class specifications for each state given in parentheses.

Sources:

- ASTM's Standard Specification for Automotive Gasoline, D-439-83.
- API's Digest of State Inspection Laws--Petroleum Products, Fourth Edition.

Table 2-9

Comparison of Post-1982 NIPER Survey Results [16] to July ASTM and State RVP Standards

	States with RVP Standards					States without RVP Standards				
	A*	A/B	B	B/C	C	A*	A/B	B	B/C	C
Max. ASTM RVP (psi)	9.0	10.0	10.0	11.5	11.5	9.0	10.0	10.0	11.5	11.5
Avg. of State RVP Standards (psi)	9.0	9.8	10.1	10.5	11.7	--	--	--	--	--
No. of States**	2	2	8	8	8	0	2	2	2	14
No. of States with Average RVPs above ASTM Specs.	2	0	7	0	1	--	0	0	0	1
No. of States with Average RVPs above State Stds.	2	0	5	1	1	--	--	--	--	--

---

* "A" through "C" designate ASTM volatility classes as defined in ASTM's D-439 and reviewed in Table 2-5.

** Hawaii and Alaska excluded due to lack of fuel survey data.

Several basic conclusions can be made from the information presented in the above discussions. One, gasoline volatility has been gradually increasing over the past two decades and no substantial data exist to indicate that this trend will not continue. Two, ASTM recommendations and State-implemented volatility limits appear to be somewhat ineffective in controlling gasoline volatility. Even if ASTM specifications were currently restricting RVP -- and they may indeed be -- there is some speculation that they could be changed in the future. Revisions have been made in the past as vehicles have been designed to handle more volatile fuels. The projected widespread use of fuel injection systems continues this trend, so a relaxation of the current ASTM RVP limits is not inconceivable. Third, the current average RVP in Class C areas is roughly 11.0 psi, which is approaching the maximum ASTM specification of 11.5 psi. Based on these observations, then, this study assumes that, by 1988, gasoline RVP will on average rise to equal the ASTM limits for each state. (Chapter 6 will address the sensitivity of this assumption by examining the cost effectiveness of the control strategies starting from a baseline RVP of 0.5 psi below ASTM limits, instead of just at the limits.)

3. Effect of Weathering on Fuel Volatility

The volatilities reported in various fuel surveys (e.g., NIPER, MVMA) represent those levels measured at the gasoline pump. However, as the gasoline in the vehicle's fuel system responds to daily diurnal temperature changes and engine heat, some of the lighter hydrocarbons are lost. Thus, the volatility of the fuel gradually decreases. This phenomenon of "weathering" is an important consideration in assessing evaporative emissions that actually occur in the field.

An EPA-sponsored study recently conducted by Southwest Research Institute (SwRI) examined the effects of weathering on the RVP of gasoline as the vehicle's fuel tank is gradually emptied. Two vehicles were driven approximately 50 miles each day and allowed to soak overnight in a shaded area; each day, the RVP of the fuel remaining in the tank was measured. This process was continued over roughly five days until the fuel tank (which started out completely full) was essentially empty. Three fuels of varying initial RVP (roughly 9.0, 10.5, and 12.0 psi) were examined. Test results indicate that, in general, as a vehicle's fuel tank goes from full to empty, the RVP of the originally dispensed fuel decreases by an average of 9 percent.[17] For example, a fuel dispensed with an RVP of 11.5 psi could weather to a final RVP of about 10.5 psi if the fuel tank was allowed to empty out completely without being refilled. Of course, this is not the norm in the field, so dispensed fuels most likely never weather to this great an extent before refueling takes place. This weathering effect appears to be independent of the fuel tested, but could vary with other test parameters (i.e., length of soak period, soak temperature, distance driven, number of trips per day, etc.).[17]

General Motors has also conducted tests examining the effect of weathering on fuel volatility and evaporative emissions. Unlike the SwRI work, chassis dynamometer tests (i.e., FTP and HFET) and standard diurnal and hot-soak cycles were used to simulate typical urban driving conditions instead of actual highway driving and 24-hour outside soaks. GM's testing of two fuels showed the original RVP to decrease from between 9 and 15 percent from tank fill-up to the empty point.[18] As mentioned earlier, most vehicles in the field are not permitted to go completely empty, so a mid-range level is probably more representative. At the 40-percent fill level specified in EPA's evaporative test procedure, GM showed an RVP decrease of 6-13 percent due to weathering.[18] According to GM's data, this change in RVP results in a decrease in uncontrolled* diurnal evaporative emissions of approximately 15 percent (again at the 40-percent fill level).[18]

At this point, the effect of weathering on fuel RVP and, thus, evaporative emissions has not been factored into this analysis. Additional work in this area is required before this could be done confidently. However, GM's estimated 15-percent decrease in diurnal emissions is used in an initial attempt to account for weathering in Appendix 2-A, which examines the effects of various environmental conditions on evaporative emission levels. Although more work is required, at this point, the absence of an explicit consideration of weathering should not have a significant net impact on the results of the study.

C. Use of Alcohol Blends

As a result of the oil crisis in the early 1970's, efforts were begun in the United States to reduce the dependence on imported oil. One idea eventually introduced was the use of alcohols in gasoline to extend the supply of gasoline. The Environmental Protection Agency (EPA), under Section 211(f) of the Clean Air Act, must approve any new unleaded fuels which are not substantially similar to fuels already permitted in the market. Since 1978, the EPA has granted waivers for two ethanol/gasoline blends and four methanol (and cosolvent)/gasoline blends. The most recent waiver granted for the DuPont application places an evaporative index (EI) limit on the waived fuel to assure that evaporative emissions do not increase compared to those with typical in-use gasolines.[19] A list of all waivers granted is shown in Table 2-10. Currently in the United States, ethanol blends comprise 6-7 percent of the total gasoline market and methanol blends comprise 3-4 percent of the total gasoline market.[20,21]

---

* "Uncontrolled" refers to the lack of an evaporative control system on the vehicle.

1. Effect on Fuel Volatility Parameters

The addition of a polar alcohol affects the properties of the non-polar gasoline to which it is added. The primary effect is on the distillation curve and, thus, the parameters associated with volatility. Three of these parameters, discussed in detail in Section IV.B of this chapter, are RVP, FEVI, and EI.

Although the exact distillation effects of alcohol addition to gasoline vary for every base gasoline, some general effects are common. Theoretically, the addition of a pure compound to gasoline causes the percent evaporated at a specified temperature, compared to the straight gasoline, to decrease at temperatures below the boiling point of the compound added. At that point, that compound is distilled off and the percent evaporated at higher temperatures (compared to straight gasoline) is increased by the presence of the compound. However, both methanol and ethanol form azeotropes with many of the components in gasoline. An azeotrope is a mixture of a particular composition of two or more components which, in the case of alcohols and gasoline, has a constant boiling point lower than that of either individual compound. The combination of these two effects causes the percent of fuel evaporated at certain temperatures to be greater for an alcohol blend than for straight gasoline, and to an extent much greater than the percentage of the alcohol alone. This effect on distillation occurs primarily in the boiling temperature range from the lowest-boiling azeotrope to the highest-boiling gasoline component forming an azeotrope.

As discussed earlier, RVP is a measurement of the volatility of a fuel at 100°F. Since the vapor pressures of methanol and ethanol are lower than gasoline at 100°F, the addition of these alcohols to a gasoline could theoretically cause the RVP of the alcohol blend to be lower than that of the straight gasoline. Once again, however, the presence of highly volatile azeotropes erases this effect and causes an increase in the RVP. The precise increase in RVP varies for every base gasoline, but the increases from each alcohol are generally similar. For the addition of methanol alone to gasoline at

Table 2-10

Clean Air Act Section 211(f) Waivers

Name	Date Granted	Limitations
1. Gas Plus Inc. "Gasohol"	12/16/78 (w/o decision)	-up to 10% (vol.) anhydrous EtOH
2. Synco 76 Fuel Corp.	5/18/82	-up to 10% (vol.) EtOH -proprietary additive
3. Sun Petroleum Products Co.	6/13/79	-up to 5.5% (vol.) of a 1:1 MeOH/TBA mixture
4. Anafuel "Petrocoal"	9/28/81	-up to 12% (vol.) MeOH -up to 6% (vol.) butanols -proprietary inhibitor
5. ARCO "Oxinol"	11/7/81	-up to 4.75% (vol.) MeOH -up to 4.75 (vol.) TBA -ratio of MeOH: TBA cannot exceed 1
6. DuPont	1/14/85	-up to 5% (vol.) MeOH -at least 2.5% (vol.) cosolvent (EtOH, propanol, butanols) -proprietary corrosion inhibitor -must meet EI specifications set for ASTM class areas

---

EtOH = ethanol.
MeOH = methanol.
TBA = tertiary butyl alcohol.

2-10 percent (by volume), the increase in RVP is around 3 psi. For the addition of methanol with a cosolvent (ethanol, propanols, and/or butanols) to gasoline at 5-10 percent of total volume, the increase in RVP is slightly less -- around 2 psi. The increase in RVP for the addition of 2-10 percent (by volume) ethanol to gasoline is around 1 psi.[11]

A second volatility measure discussed earlier is FEVI. The addition of alcohol to gasoline will increase the FEVI by the same amount as the RVP is increased, plus by an additional amount due to the increase in volatility at 158°F ($\%_{158}$). From a review of data, it appears that for both methanol and ethanol blends allowed by waiver, the $\%_{158}$ is increased by roughly 10-15 percent, resulting in an additional 1.3- to 2-psi increase in the FEVI.[10,22-24] (Typical distillation curves for methanol and ethanol blends are shown in Figures 2-4 and 2-5). The total increase in FEVI is around 4.3-5 psi for a methanol blend, approximately 3.3-4 psi for a methanol with cosolvent blend, and approximately 2.3-3 psi for an ethanol blend.

A third volatility measure discussed earlier is EI. The addition of alcohol to gasoline will increase the EI because of the resulting increase in RVP and an increase of 5-10 percent in the $\%_{200}$.[10,22-24] (See Figures 2-4 and 2-5). However, the effect of alcohol on the $\%_{100}$ is rather unpredictable. In some cases the alcohol causes the $\%_{100}$ to decrease by 1-2 percent, but in many cases neither the gasoline nor the alcohol has begun to boil at 100°F. The combination of the alcohol effects produces increases in EI over the straight gasoline of approximately 3-4 psi for methanol blends, 2.5-3 psi for methanol with cosolvent blends, and 1.5-2 psi for ethanol blends.

The effects of alcohol addition on RVP, FEVI and EI can be counteracted by adjusting the contents of the gasoline to which the alcohol is added. By removing lighter hydrocarbons (such as butanes and/or pentanes), the RVP, $\%_{158}$, FEVI or EI of the final blend can be controlled to levels of the original straight gasoline. However, the evaporative emissions of automobiles using the volatility-controlled alcohol blends could still be significantly greater than straight gasoline, as some data show.

2. Effect on Evaporative Emissions

The reported effects of alcohol blends on evaporative emissions vary widely and can be examined in two ways: 1) by comparing a gasoline and a volatility-controlled blend of equal RVP, FEVI or EI, and 2) by comparing a gasoline and a high-RVP

Figure 2-4

Typical Methanol Blend Distillation Curves [22]

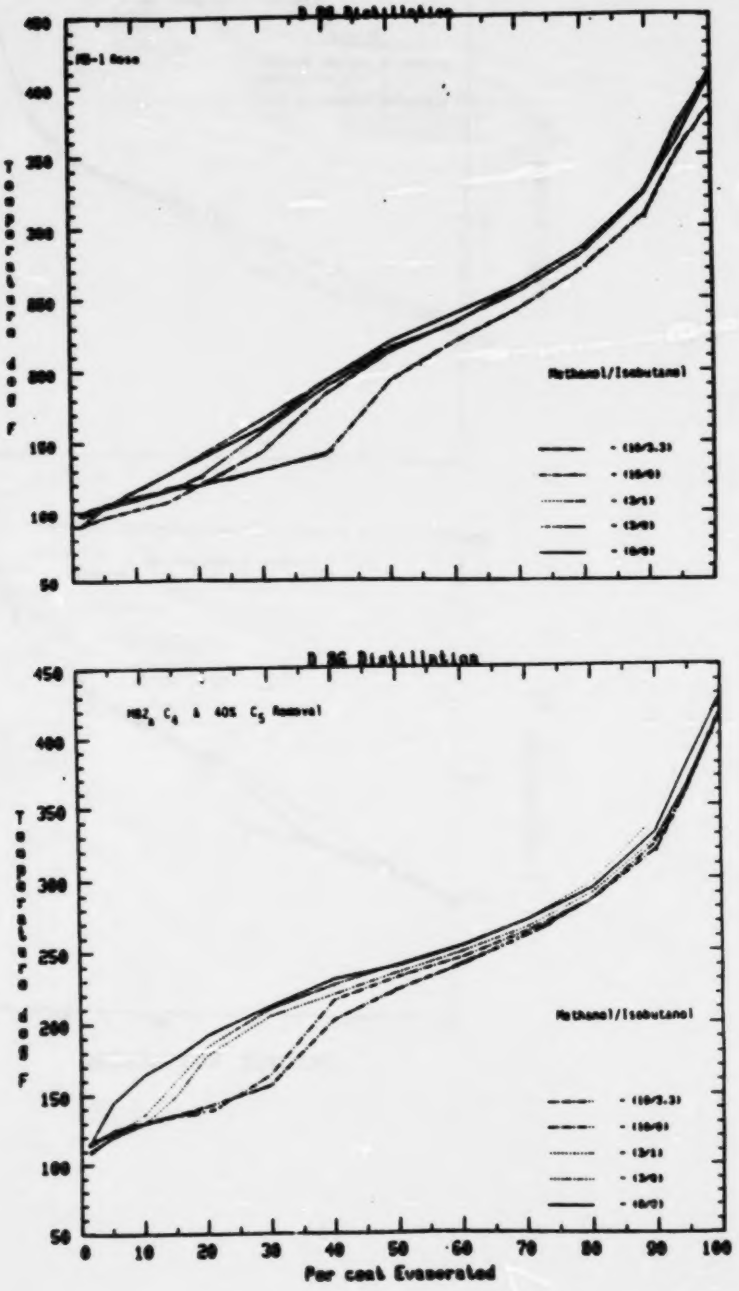
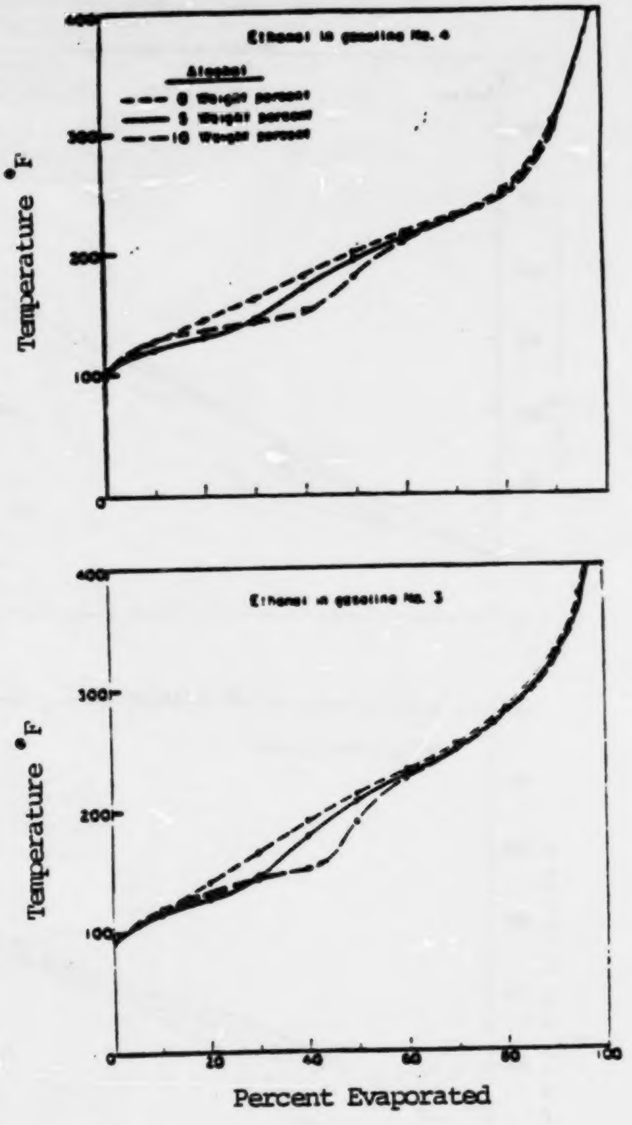


Figure 2-5

Typical Ethanol Blend Distillation Curves [23]



blend in which the alcohol (with or without cosolvent) is simply splash-blended into a similar gasoline. In the first case, the results for methanol blends show anywhere from no effect to a 95-percent increase in evaporative emissions with the volatility-controlled blend over the straight gasoline.[11,22,25,26] For the second case, the reported increase in evaporative emissions with the methanol blend is between 40 percent and 325 percent.[26-28]

Reported increases in evaporative emissions with the use of ethanol blends also vary widely. In the controlled volatility case, the increases in evaporative emissions reported for ethanol blends are between 25 percent and 170 percent.[29,30] For the splash blend case, evaporative emissions are reported to increase between 5 and 220 percent.[29-34] Currently, ethanol can be added directly to gasoline without any legal requirement for volatility controls, whereas methanol blends generally must meet the same ASTM specifications applicable to gasoline.

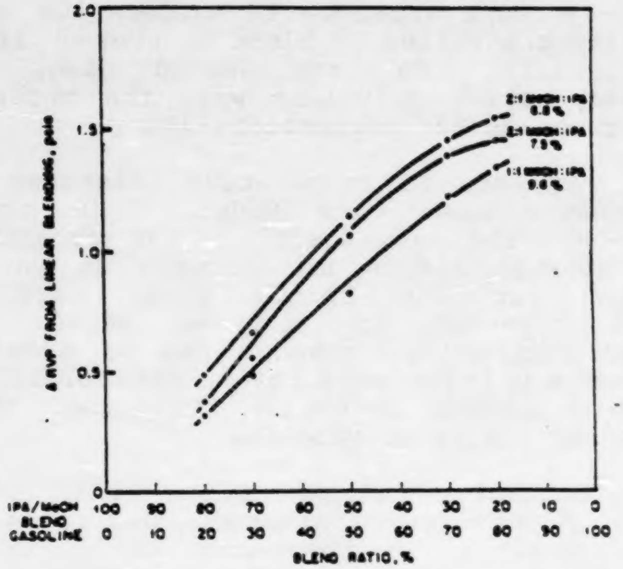
Even with control of alcohol blend volatility, there can be an increase in evaporative emissions due to intermittent use of blends and gasoline. A phenomenon called commingling can occur when an alcohol blend is added to a tank partially filled with straight HC gasoline, wherein the RVP of the mixture can be significantly higher than the RVP of the original gasoline or blend. Commingling is depicted in Figure 2-6, where the increase in RVP (over the straight HC gasoline level) is shown as a function of blend ratio and type of blend. For example, in the top plot, if a 1:1 MeOH/isopropyl alcohol blend (9.6% by volume) is added to fill a 60-percent full tank of straight HC gasoline, the RVP of the new mixture (i.e., full tank) will be roughly 1.0 psi higher than that of the original straight HC gasoline.

This commingling effect could possibly lead to increased evaporative emissions. One report calculated an average increase of 33 percent in evaporative emissions due to the intermittent use of Oxinol in every third tank, if both the Oxinol and gasoline had the same RVP.[11] The increase in evaporative emissions due to commingling has been shown to be a function of the percentage of stations selling blends, the amount of fuel remaining in the fuel tank when refilling, and the habits of the buyer (i.e., whether fuel is bought at random or loyally).

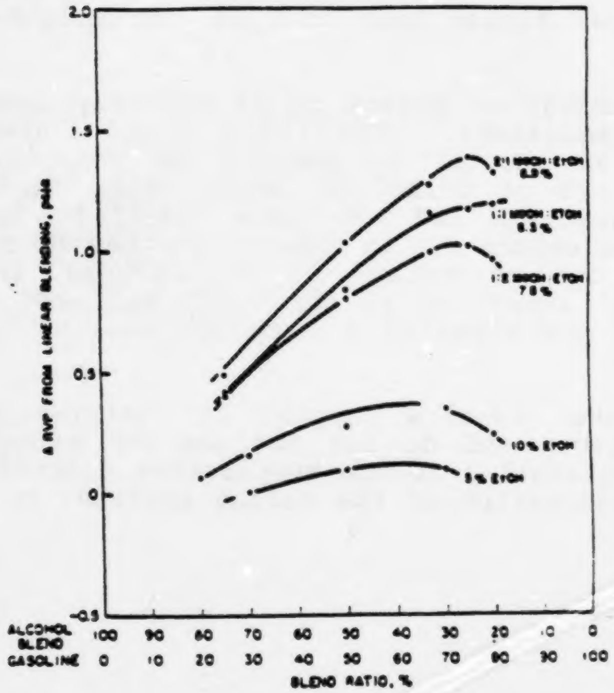
The above results apply to short-term evaporative emissions impacts and do not include any effects which could arise from degradation of the evaporative control system due to methanol contamination of the carbon canister through long-term

Figure 2-6

COMINGLING VAPOR PRESSURE EFFECTS MeOH/IPA BLENDS WITH ALL HYDROCARBON GASOLINE



COMINGLING VAPOR PRESSURE EFFECTS EtOH AND MeOH/EtOH BLENDS WITH ALL HYDROCARBON GASOLINE



Source: ARCO Petroleum Products Company, March 12, 1985
(in letter to Craig Harvey, EPA)

use of alcohol blends. There has been widespread speculation about contamination of charcoal with alcohols, but several studies have failed to show a definitive effect on the working capacity of the canister.

For methanol blends, most reports (including recent EPA contract work) show no substantial difference in canister working capacity when compared to the use of straight gasoline, even with high mileage accumulation.[26,35,36] (Prior EPA contract work on canisters in a laboratory situation had shown an effect of the blends on the working capacity, but this could be attributed to a difference in loading of the canisters during the experiment.)[37] One report does state that the use of methanol blends can decrease the working capacity of carbon, resulting in increased evaporative emissions.[27] However, the mileage accumulation fuel was a splash blend, and thus, the effect could be due to higher volatility. Possible alcohol effects have been attributed to the formation of azeotropes between methanol and heavier hydrocarbons. These azeotropes are more volatile than either component and become adsorbed on the carbon. Then, apparently, the methanol breaks off and leaves the hydrocarbon portion attached to the carbon, which is difficult to purge.[38]

The reported effects of ethanol blends on carbon canisters are limited, but suggest no degradation of working capacity. The reports did show that ethanol was adsorbed in preference to some hydrocarbons and that a lesser degree of regeneration was achieved during a defined purge period; however, an extended purge period tended to remove all the ethanol.[30]

3. Summary

The addition of alcohols to gasoline affects the properties of the blend. The addition of either methanol or ethanol results in higher percentages of fuel to be evaporated at given temperatures, and greater RVP, FEVI, and EI values. The effects of methanol on these parameters are more dramatic than for ethanol.

This increase in volatility can cause higher evaporative emissions during the use of alcohol blends. However, some reports show that controlling the volatility characteristics of the blend to that of current gasolines is sufficient to keep evaporative emissions at current levels and prevent any permanent reduction in working capacity.

The intermittent usage of blends also causes an increase in evaporative emissions because of the nonlinearity in RVP upon mixing alcohol blends and gasoline (i.e., the commingling effect). Thus, even if the RVP of alcohol blends is controlled to current gasoline levels, the amount of evaporative emissions could theoretically still increase. However, this study does not take the commingling effect into account, and alcohol blends are treated essentially as straight gasolines of equal volatility.

D. Ambient Temperature Conditions

In addition to weathering, ambient temperature conditions can also impact the level of evaporative emissions. Diurnal losses are dependent upon not only the ambient temperature excursion (daily maximum minus daily minimum), but also on the absolute magnitude of these temperatures. Hot-soak losses are also dependent on ambient temperature. For example, a vehicle undergoing a 30°F diurnal change at an average temperature of 90°F would be expected to have significantly greater diurnal and hot-soak losses than a vehicle experiencing only a 15°F diurnal difference at an average temperature of 75°F. In an effort to quantify the magnitude of such differences, an EPA-sponsored test program was initiated several months ago to measure diurnal and hot-soak losses at various ambient temperature conditions.

This test program (currently being conducted for EPA at the Automotive Testing Laboratories, or ATL) includes a matrix of three fuel RVPs, three diurnal starting temperatures, four diurnal temperature excursions, and three average hot-soak temperatures.[39,40] However, some vehicles are being tested over only part of the full matrix in the interest of including more vehicles in the sample. The standard EPA test procedure (i.e., diurnal temperatures between 60°F and 84°F, and average hot-soak temperature of roughly 82°F) is represented in the full test matrix. Preliminary analysis of test data on 24 light-duty vehicles certified to the 2-gram standard suggests that increasing the diurnal temperature excursion from 24°F to 30°F can increase controlled diurnal losses by a factor of 1.3 to 2.7, depending on the starting temperature, the RVP of the fuel, and the fuel metering system (carburetor or fuel-injector). Data on these 24 vehicles also indicate that an increase in ambient temperature from 70°F to 82°F can increase controlled hot-soak losses by 29-60 percent, again depending on fuel RVP and fuel metering system. It should be noted that these data are preliminary; testing on more vehicles (most over only part of the full test matrix) is set to be completed by the end of this year.

Diurnal emissions data on these 24 vehicles are anlayzed in Appendix 2-A at the end of this chapter. There, the diurnal averages are compared to theoretical emissions indexes calculated for each ATL test condition via a diurnal emissions model developed and published in 1967.[41] This model, which uses the Ideal Gas Law to predict uncontrolled diurnal losses as a function of fuel characteristics and temperatures, is used in Appendix 2-A to relate the various ATL test conditions to the standard EPA test procedure in terms of relative predicted diurnal emissions. This model is also used there to compare typical summertime temperature and RVP conditions in several of the ozone non-attainment areas to EPA's current evaporative test procedure. Relative diurnal emissions indexes are calculated for 17 selected cities in the last section of Appendix 2-A. More details on the methodology and inputs used are provided there.

As with weathering (discussed earlier), the preliminary nature of these results have prevented the effects of ambient temperature conditions on the level of evaporative emissions from being accounted for in the emissions projections made in this report. Work continues in both of these areas (i.e., temperature and weathering) in hopes of incorporating their effects into future analyses.

V. Results of In-Use Motor Vehicle Testing

This section presents test data from EPA's in-use motor vehicle emission factor (EF) program in an attempt to quantify the effect of the factors mentioned in the previous section (i.e., fuel volatility and evaporative control system design) on emissions from current vehicles. The section begins with a brief description of the current evaporative test procedure used in certification and changes made for the in-use EF program (i.e., the addition of commercial fuels and the switch in fuel sequence). Next, general evaporative emission results from the EF program are presented for various RVP levels with a comparison between the revised estimates and the MOBILE3 figures published in June 1984. In the following section, these revised hot-soak and diurnal emission levels are broken down into several basic components of motor vehicle evaporative emissions, based on an analysis of the vehicle test fleet. By attributing certain portions of current total evaporative losses to different sources (i.e., excess RVP, malmaintenance/defect, improper design of purge system, etc.), it is possible to estimate the effect that changes in in-use RVP or certification fuel and test procedure will have on each component and, thus, on total evaporative emissions. (The effects of the various control strategies will be outlined, in detail, for various model years in Chapter 5). Also, as discussed in the final part of this section, exhaust HC and CO emissions have been found to be dependent upon RVP; this effect is quantified in this final section. (Again, the specific adjustments that have been made to MOBILE3 exhaust EFs to account for the RVP effect under various control strategies are detailed in Chapter 5.)

A. Test Procedure

The standard evaporative test procedure used in the certification of new vehicles is outlined in detail in Part 86 of Title 40 of the Code of Federal Regulations (40 CFR 86). Briefly, the vehicle is first drained of its fuel and refueled with Indolene (with an average RVP of 9.0 psi) to the 40-percent full level. The vehicle is then preconditioned using the Urban Dynamometer Driving Schedule (also referred to as the "LA-4" cycle), which lasts approximately 23 minutes; under special circumstances (e.g., if the vehicle was transported via carrier instead of being driven to the test site), manufacturers can request up to three LA-4 cycles to assure adequate purging of the evaporative canister. Following preconditioning, the vehicle is stored (or "soaked") for a period of 12-36 hours before the SHED (Sealed Housing Evaporative Determination) test is conducted.

Just prior to beginning the SHED test for diurnal losses, the vehicle is drained and refueled with chilled Indolene to the 40-percent fill level.* Beginning with a fuel and tank temperature of 60°F, the fuel is heated to 84°F over a period of one hour, at which time the final HC concentration in the SHED enclosure is recorded as the total diurnal loss.

Following the diurnal test, a cold-start LA-4, followed by the first half of a hot-start LA-4 is performed, during which exhaust emissions are measured. At the completion of these tests, the engine is shut off and the vehicle is pushed into the SHED enclosure for the hot-soak test. The test vehicle remains there for one hour at an average ambient temperature of 81°F** and the increase in HC concentration is recorded and converted into a total hot-soak mass emission.

The estimation of evaporative emissions as a function of fuel RVP used to evaluate the control options examined in this study was based on data generated as part of EPA's ongoing in-use emission factor (EF) test program. This program involves the testing of in-use (privately-owned) passenger cars, selected at random from State of Michigan vehicleregistration files. Prior to November 1983, in-use (privately-owned) vehicles were evaluated for hot-soak and diurnal losses only while operating on certification test fuel (Indolene) with a 9.0-psi RVP. Since then, however, the effect of fuel volatility on emissions has been examined with the addition of two commercial fuels with nominal RVPs of 11.5 psi (added in November 1983) and 10.5 psi (added in August 1984).

---

* The fuel is chilled to about 50°F to counteract the warm fuel tank (70-75°F), which is already warmer than the lower end of the temperature excursion (60°F).

** The hot-soak temperature range specified in the CFR is 68-86°F.

The test procedure used in the EF program has basically followed certification practices except for certain differences in vehicle preconditioning and, of course, the addition of commercial fuels. (These in-use EF test sequences are summarized in Table 2-11). Between November 1983 and July 1984, vehicles were preconditioned over a shortened LA-4 cycle which lasted only 10 minutes instead of the entire 23 minutes. Commercial fuel with an 11.5-psi RVP was added to the test sequence following all evaporative and exhaust emission tests conducted on Indolene.

In July 1984, the shortened prep cycle was dropped and the entire LA-4 cycle (used in certification) was reinstated. Also, at this time, it was concluded that the evaporative tests on 11.5-psi commercial fuel may have been unrepresentative because they were run following a battery of tests on 9-psi Indolene over which the evaporative canister was repeatedly purged. Therefore, the commercial test was begun with an essentially "unloaded" canister, which would probably bias results toward lower emissions than those experienced in the field. Further, because vehicles had been operated on 11.5-psi commercial fuel prior to arriving at EPA, it follows that the most accurate measurement of in-use emissions would be obtained by testing commercial fuel first. Therefore, the test sequence was changed and the 11.5-psi fuel was tested first, followed by Indolene.

In August 1984, testing of the mid-range commercial fuel with an RVP of roughly 10.5 psi was added to the sequence just after the 11.5-psi fuel and before any Indolene testing. Other minor changes (initiated in July 1984) involve the storage of the vehicle prior to any evaporative tests. To avoid premature saturation of the canister, the gas cap is loosened to allow vapors to bypass the control system and the vehicle is stored inside at a fairly constant temperature.

Table 2-11

Comparison of In-Use Test Sequences

Nov. 83 - July 84	Post - July 1984
1. Park indoors and/or outdoors	1. Park indoors; loosen gas cap.
2. Shortened dynometer prep (10-min.)	2. LA-4 dynometer prep (23-min.)
3. Indolene evaporative tests	3. Commercial (11.5 psi) evaporative tests
4. Exhaust emission tests (HFET and short tests)	4. Mixture (10.5 psi) evaporative tests*
5. Commercial (11.5 psi) evaporative tests	5. Indolene evaporative tests
	6. Exhaust emissions tests (HFET and short tests)

---

* 10.5 RVP added in August 1984.

B. General Test Results

Vehicle samples used in EPA's in-use EF testing both prior to and after the July 1984 test procedure changes are broken down by manufacturer in Table 2-12.* Carbureted and fuel-injected samples are outlined separately, and sample distributions are compared to 1984 market shares.

Evaporative emissions from these test vehicles are summarized in Table 2-13. Results are shown for both Indolene and commercial (11.5-psi) fuels, and are separated out by vehicle type and test procedure. The MOBILE3 emission rates published in June 1984 are from a subset of the November 1983-July 1984 tests and are listed separately for comparison. Revised MOBILE3 estimates are listed as July 1984 - April 1985 results.

As indicated from the results shown in Table 2-13, the change in the test procedure has led to slightly lower emissions with Indolene and somewhat higher emissions with commercial fuel in almost all cases. (This is as to be expected from the previous discussion on the reasons behind the changes in fuel test sequence.) For fuel-injected vehicles, higher emissions also may be partially due to the higher average mileage of the vehicles being tested; the vehicles tested after July 1984 have an average mileage over twice that of those tested previous to that time. Results of the July 84 - April 1985 testing are shown graphically in Figure 2-7, which plots revised hot-soak and diurnal emissions versus fuel RVP.

Both sets of vehicles tested show average emissions exceeding the 2-gram standard for total evaporative emissions, even while operating on Indolene: carbureted vehicles averaging 4.64 grams/test and fuel-injected vehicles averaging 2.15 grams/test. When tested on 11.5-psi commercial fuel, these evaporative emissions are much larger: 12.85 grams/test for carbureted vehicles and 7.34 grams/test for fuel-injected vehicles. The possible causes of the excess evaporative emissions are the subject of discussion in the following section.

---

* The post-July 1984 vehicle sample includes vehicles tested only through April 1985, the point at which test results were "frozen" for this analysis. Subsequent test results are currently being analyzed.

Table 2-12

In-Use EF Vehicle Sample Distribution

	Carbureted			Fuel-Injected		
Manufacturer	Nov. 83-July 84	July 84-April 85	1984 Market Share	Nov. 83-July 84	July 84-April 85	1984 Market Share
GM	31(33%)	32(29%)	46%	57(74%)	15(27%)	42%
Ford	38(41%)	26(24%)	13%	9(12%)	2(4%)	25%
Other Domestic*	12(13%)	17(16%)	11%	--	13(24%)	11%
Toyota	2(2%)	13(12%)	4%	--	13(24%)	10%
Nissan	3(3%)	14(13%)	5%	3(4%)	8(14%)	9%
Other Imports**	7(8%)	7(6%)	21%	8(10%)	4(7%)	3%
Total	93(100%)	109(100%)	100%	77(100%)	55(100%)	100%

---

* AMC, Chrysler, VWA.

** Honda, VWG, Mitsubishi, Toyo-Kogyo, Audi.

Table 2-13

Comparison of Evaporative EF Test Data from Non-Tampered Vehicles (g/test)

Indolene (RVP = 9.0 psi)

Test Period	Technology	N	Mileage	Diurnal	Hot-Soak
Nov 83 - July 84	Carb.	93	45000	4.16	2.19
	Fuel-Inj.	77	20000	1.64	0.96
Published MOBILE3*	Carb.	53	60000	4.22	2.74
	Fuel-Inj.	62	20000	2.21	1.12
July 84 - April 85**	Carb.	109	55000	2.32	2.32
	Fuel-Inj.	55	46000	1.25	0.90

Commercial Fuel (RVP = 11.5 psi)

Test Period	Technology	N	Mileage	Diurnal	Hot-Soak
Nov - July 84	Carb.	93	45000	8.64	3.29
	Fuel-Inj.	77	20000	2.33	1.28
Published MOBILE3*	Carb.	53	60000	9.31	3.98
	Fuel-Inj.	62	20000	3.13***	1.55
July 84- April 85**	Carb.	109	55000	9.01	3.84
	Fuel-Inj.	55	46000	5.51	1.83

---

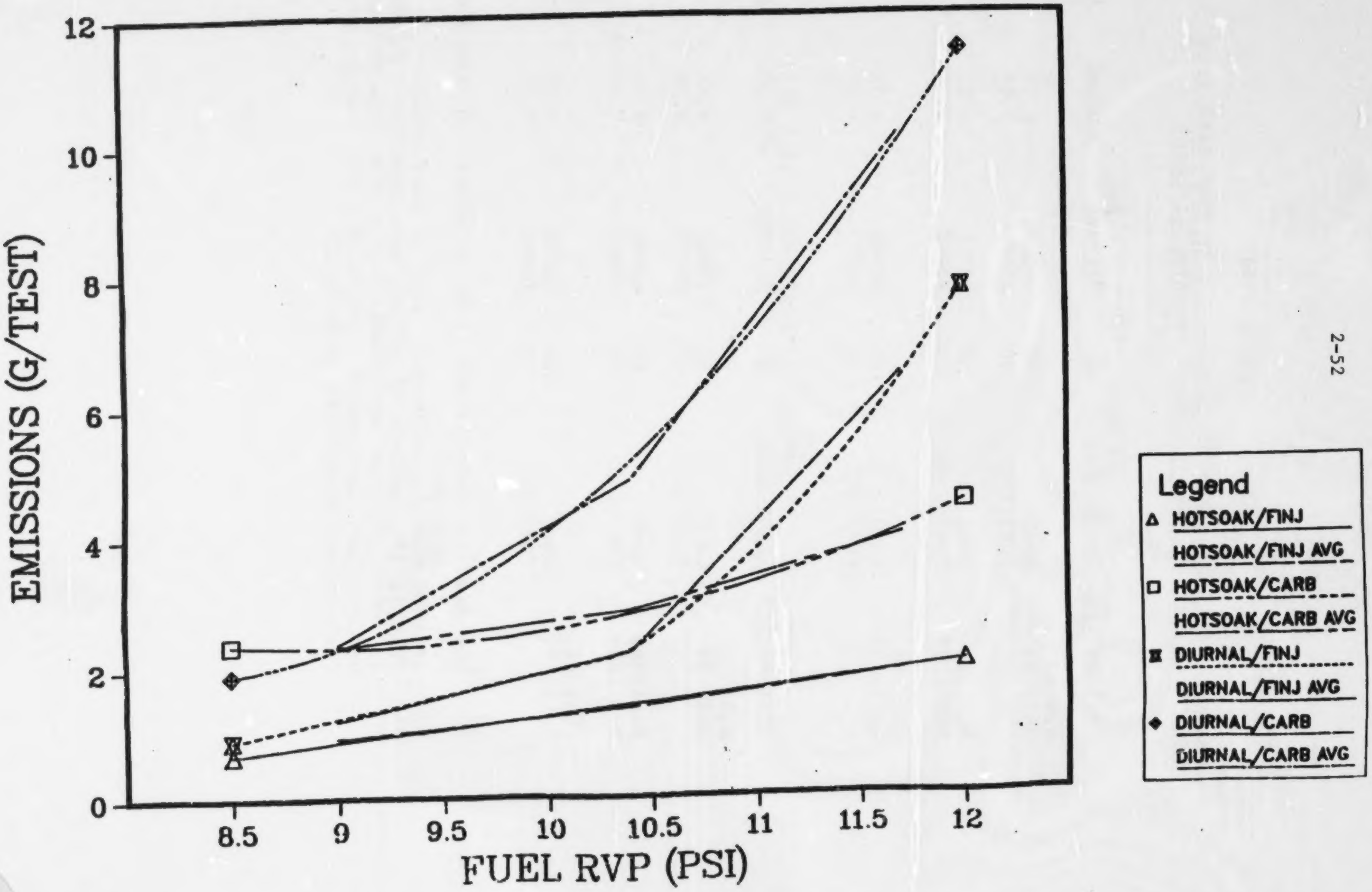
* The MOBILE3 results are from a subset of the Nov. 83 - July 84 data pool.

** Revised MOBILE3 estimates, used in this study.

*** This is the average of actual test results. However, due to uncertainties associated with the low mileage, the value for carbureted vehicles was also used for fuel-injected vehicles in MOBILE3.

Figure 2-7

EVAPORATIVE EMISSIONS VS. FUEL RVP



C. Components of Excess Motor Vehicle Evaporative Emissions

For purposes of analysis, it is useful to segregate the evaporative emission excess described above according to its probable causes. Using EF test data, these four basic categories were chosen as: 1) effect of insufficient design capacity/purge, 2) effect of malmaintenance and defects, 3) effect of excess RVP, and 4) effect of evaporative system tampering. The causes and magnitude of each of these effects (for current vehicles) are detailed below; more information on the methodology used to separate these four sources is provided in Appendix 2-B.

1. Insufficient Design Capacity/Purge

Even with properly functioning evaporative emission control systems, many current vehicles fail to meet the 2-gram standard on Indolene. This is primarily seen in carbureted vehicles which average 2.75 grams/test when there are no apparent malfunctions.* Conceivably, this failure could be due to an insufficient capacity to store or purge vapors inherent in the system design. It may also be valid to attribute some of these excess emissions to lingering effects of high RVP fuels and alcohols on charcoal working capacity. (However, as discussed in Section IV, the effects of low-level alcohol blends and the use of high RVP fuels do not appear to be long lasting.)

The plausibility of insufficient design capacity and purge is evident from the limitations of the evaporative emission test procedure and certification process. To be certified, a vehicle must meet the standard after applying an additive deterioration factor to low mileage emission test data. Also, MSAPC Advisory Circular No. 50A states that vehicles should be able to pass the evaporative emission test when starting the test sequence with a saturated canister. (Many EF vehicles are probably received in this condition.) This means that purge systems should be designed to completely purge a loaded canister with the LA-4 prep cycle. However, there is no requirement for this in the certification test procedure. Thus, it is possible that a certification vehicle, as currently designed, would fail were it to begin the test with a saturated canister.

---

* As shown in Appendix 2-B, Table 2-B-2, for "problem-free" vehicles (to be explained in the next few paragraphs).

The derivation of the magnitude of the insufficient design capacity/purge effect is detailed in Appendix 2-B. The general concept involved was to compare the average emission levels of the "problem-free" vehicles, as defined in Table 2-14, with the standard level of 2 grams/test for total evaporative emissions. The difference between the two levels was assumed to be due to the emission control system design. Summarized in the top portion of Table 2-15, this effect is not seen in fuel-injected vehicles, but averages 0.70 grams/test for carbureted light-duty vehicles. This effect of insufficient design capacity and purge is noted here because it presumably would be eliminated for new vehicles by revising the evaporative emission test procedure to require that a vehicle begin the test with a saturated canister.

2. Malmaintenance and Defects

Non-tampered vehicles with the maintenance problems and hardware defects listed in Table 2-14 (tampering is considered separately below) will generally have higher evaporative emissions than well-maintained vehicles. These problems can lead to either a partial increase in emissions (e.g. from a dirty canister filter) or to completely uncontrolled emissions (e..g., from an inoperative canister purge solenoid or valve). On average, excess emissions would not be expected to be as high as the uncontrolled emission baseline because some purging would still occur. This is different from the case of tampering where complete system disablement is generally the result.

The magnitude of the effect of malmaintenance and defects for current vehicles operating on Indolene is estimated by considering the difference between the non-tampered EF vehicle sample average and the problem-free vehicle sample average tested on Indolene. Inherent in this calculation is the assumption that the EF sample has a representative malmaintenance and defect rate. For carbureted vehicles (see Table 2-16), the malmaintenance and defect rate from EF cars tested since July 1984 (32 percent) is within the range and essentially equal to the average of all other available data samples. For fuel-injected vehicles, the newer EF sample has a slightly higher rate than the other samples (e.g., 16 percent versus only 5 percent in the pre-July 1984 in-use EF sample). However, this is probably due to the fact that the fuel injected vehicles in the old EF sample averaged fewer total miles on their odometers than those in the current sample (20,000 vs. 46,000). Overall, then, the malmaintenance and defect rates in the July 1984 - April 1985 EF sample appear representative.

Table 2-14

Conditions Excluding Vehicles From Problem-Free Sample

I. Fuel System

- A. Carburetor Assembly
  1. Loose on Manifold
  2. Leaks Fuel
  3. Exceptionally Dirty
- B. Fuel Injection Components
  1. Injectors Leaking

II. Evaporative System

- A. Canister
  1. Saturated with Fuel
  2. Broken
  3. Missing*
- B. Canister Filter
  1. Dirty
  2. Saturated with Fuel
  3. Missing
- C. Canister Purge Solenoid/Valve
  1. Leaks Vacuum
  2. Sticking
  3. Inoperative
  4. Missing*
  5. Disconnected*
- D. Hoses, Lines, Wires
  1. Vacuum Line Plugged
  2. Vacuum Line Disconnected*
  3. Vacuum Line Damaged
  4. Vacuum Line Misrouted*
  5. Vent Line Damaged
  6. Vent Line Disconnected*
- E. Other
  1. EFE TVS Stuck Open/Closed
  2. Non-OEM Gas Cap
  3. Bowl Vent Control Valve Always Open/Closed
  4. VCV Vacuum Control Valve Inoperative
  5. Gas Cap Leaks
  6. Sending Unit Gasket Leaking
  7. Fuel Tank Rollover Valve Leaking
  8. Air Cleaner Assembly Gasket Broken/Missing
  9. EFE Control Switch Missing*
  10. Gas Cap Missing*

---

* Considered to be tampering.

Table 2-15

Magnitude of Excess Evaporative Emissions from Current Vehicles (g/test)

Insufficient Design Capacity/Purge Effect

Vehicle Class	Fuel Metering System	Diurnal	Hot Soak
LDV/LDT	Carb	0.30	0.40
	FI	0.00	0.00
HDV	Carb	0.48	0.64

Malmaintenance/Defect and Excess RVP Effects

Vehicle Class	RVP	Fuel Metering System	Malm./Defect		Excess RVP	
			Diurnal	Hot Soak	Diurnal	Hot Soak
LDV/LDT	9.0	Carb	1.11	0.83	0.00	0.00
		FI	0.34	0.29	0.00	0.00
	9.5	Carb	1.21	0.91	0.62	0.06
		FI	0.44	0.42	0.24	0.05
	10.0	Carb	1.31	0.99	1.54	0.20
		FI	0.54	0.55	0.48	0.11
	10.5	Carb	1.41	1.07	2.78	0.42
		FI	0.64	0.67	0.79	0.18
	11.0	Carb	1.51	1.15	4.33	0.73
		FI	0.74	0.80	2.03	0.24
	11.5	Carb	1.61	1.24	6.19	1.11
		FI	0.84	0.93	3.76	0.29
HDV	9.0	Carb	1.77	1.32	0.00	0.00
	9.5	Carb	1.93	1.45	0.98	0.09
	10.0	Carb	2.09	1.58	2.46	0.31
	10.5	Carb	2.25	1.71	4.43	0.67
	11.0	Carb	2.41	1.84	6.90	1.15
	11.5	Carb	2.57	1.97	9.85	1.77

Table 2-16

Malmaintenance and Defect Rate Comparison

	Carbureted		Fuel Injected	
Sample	Sample Size	Defect Rate	Sample Size	Defect Rate
EF (new)*	108	32%	55	16%
EF (old)**	93	44%	77	5%
SwRI[42]	27	26%	--	--
API (NIPER)[43]	19	11%	32	13%
API (ATL)[44]	28	25%	10	0%
Average***	--	33%	--	10%

---

* Vehicles tested on three fuels w/LA-4 prep, commercial fuel first; July 1984-April 1985.

** Vehicles tested on two fuels w/10-minute prep, Indolene fuel first; November 1983-July 1984.

*** Sample-size weighted.

While the above methodology appears satisfactory for estimating the magnitude of the malmaintenance/defect effect for vehicles operating on 9-psi Indolene, it is expected that the effect would increase with the level of in-use RVP. The same would be true for a tampered vehicle. Basically, if excess emissions are being released from the canister or elsewhere, increased vapor loadings that result from higher in-use RVPs will lead to increased emissions. While redesigning vehicles for higher RVP fuel should lower emissions when the control system is fully operable, the effect of malmaintenance or a defect would be expected to be independent of the RVP for which the vehicle was designed and dependent only on the RVP of the fuel actually used.

Estimation of the magnitude of this effect at various RVPs is described in detail in Appendix 2-B; the results are summarized here in the center portion of Table 2-15. This effect can be quite large with 11.5 RVP fuel -- approaching 3 grams/test for carbureted light-duty vehicles and 2 grams/test for light-duty fuel-injected vehicles.

While the insufficient design/purge and excess RVP effects (discussed below) are assumed to be totally eliminated in new vehicles via changes to certification fuel and test procedure, the malmaintenance/defect effect can only be controlled through reduction of in-use fuel volatility or through an effective evaporative system inspection and maintenance program.

3. Excess RVP Effect

The excess RVP effect is defined as the emissions impact of operating vehicles on a fuel of higher volatility than that for which their evaporative control systems have been designed. Canisters and purge systems on current vehicles are designed to meet the 2-gram evaporative standard if operated on 9.0 RVP Indolene over the standard certification test procedure. However, as discussed in Section IV of this chapter, the RVP of current in-use gasoline in many of the ozone non-attainment areas of the country is significantly higher than 9.0 psi. Because of their higher volatilities, these commercial fuels emit more evaporative HCs than the vehicles' canisters can accommodate, which results in canister saturation and "breakthrough" of HC vapors to the atmosphere.

The magnitude of this excess RVP effect can be calculated by first subtracting total average emissions of the non-tampered sample on Indolene from those on commercial fuel. However, because part of this difference between commercial and Indolene emissions has already been accounted for in the malmaintenance and defect effects, an adjustment to the total difference is needed. The difference between the malmaintenance/defect effect on Indolene and commercial fuel must be subtracted from the total difference between non-tampered emissions at Indolene and commercial fuel to yield the excess RVP effect. This is explained in more detail in Appendix 2-B.

The magnitude of this remaining excess RVP effect on current vehicles is shown in Table 2-15 (along with the other two effects). With an in-use fuel RVP of 11.5 psi, the excess RVP effect is 7.30 and 4.05 grams/test for carbureted and fuel-injected light-duty vehicles, respectively. These represent respective increases of 265 percent and 103 percent from the 2 gram/test standard level.

As with the insufficient design/purge effect, this excess RVP effect is assumed to be completely eliminated for new vehicles if certification fuel RVP is raised to a level equal to or greater than in-use fuel RVP. However, for vehicles certified prior to any change in certification fuel RVP (i.e., 1990 in this analysis), the excess RVP effect will remain and be dependent upon in-use RVP.

4. Tampering Effect

Intentional system disablement also contributes toward excess evaporative emissions. EPA's in-use EF sample is not thought to have a representative number of tampered vehicles, since those who tamper with their emission controls may generally be reluctant to lend their vehicles to EPA for testing. The EF sample is also relatively small due to the high cost of emission testing. For these reasons, tampering rates to be used in emissions modeling are developed from EPA tampering surveys involving thousands of vehicle inspections. Those conditions considered as tampering are primarily disconnected, misrouted or missing hoses, missing canisters and missing fuel caps (as indicated previously in Table 2-14).

Because emissions from tampered vehicles are not developed from the EF sample, the MOBILE3 program accommodates them separately. Tampering incidence rates are developed from survey data and excess emissions are determined from emission tests on completely disabled systems. Since the original MOBILE3 estimates were published in June 1984, additional tampering data has become available that has allowed improvement over the June 1984 estimates. These revisions to the MOBILE3 tampering estimates are discussed below.

The original MOBILE3 LDV tampering incidence rates published in June 1984 were based on a linear regression of tampering frequency versus mileage using the results of EPA's 1982 Tampering Survey.[45] For LDTs and HDVs, the rate of increase of tampering with mileage for LDVs was applied to the average LDT-sample tampering frequency and vehicle mileage, because the LDT sample was too small to derive a change in tampering over time and no HDVs were surveyed. The zero-mile tampering rates, however, were developed from the LDT sample; these LDT zero-mile rates were also used for HDVs.

As mentioned above, updated EPA survey results from 1983 and 1984 have since become available, so these data were added to the 1982 tampering data used to develop the June 1984 MOBILE3 estimates.[46,47] The resulting information was sufficient to develop separate tampering rate estimates for both LDVs and LDTs; the HDV rates were still assumed to be the same as those for LDTs. Additional revisions to the MOBILE3 tampering estimates include the designation of vehicles with misrouted hoses and missing fuel caps as tampered vehicles.* Since these conditions were not considered as tampering in the June 1984 version of MOBILE3, previously estimated effects of tampering may have been somewhat understated. Plots of the revised MOBILE3 tampering rates versus mileage for LDVs and LDTs are shown, respectively, in Figures 2-8 and 2-9.

One possible form of tampering/malmaintenance that still remains to be investigated is the use of replacement gas caps not meeting the same specifications as the original gas cap (referred to as non-OEM (original equipment manufacturer) gas caps). Such gas caps may not seal properly and could result in either partially or completely uncontrolled emissions. The extent of their use and their effect on emissions is currently being investigated.

In addition to revising tampering incidence rates, the emission rates for tampered vehicles have also been modified by supplementing the pre-June 1984 data with more recent data and by incorporating emission excesses associated with missing fuel caps. With certain exceptions, it is assumed that all types of tampering result in completely uncontrolled emissions. A case in which this assumption may not be strictly valid is for the disconnection of a carburetor bowl vent line at the carburetor end (i.e., not at the canister). In this case, only hot-soak

---

* As misrouted hoses and missing fuel caps could be unintentional, there remains some question as to whether they should be considered "tampering" or "malmaintenance". However, as these conditions were not felt to be properly represented in the EF sample, they are currently regarded as tampering.

Figure 2-8

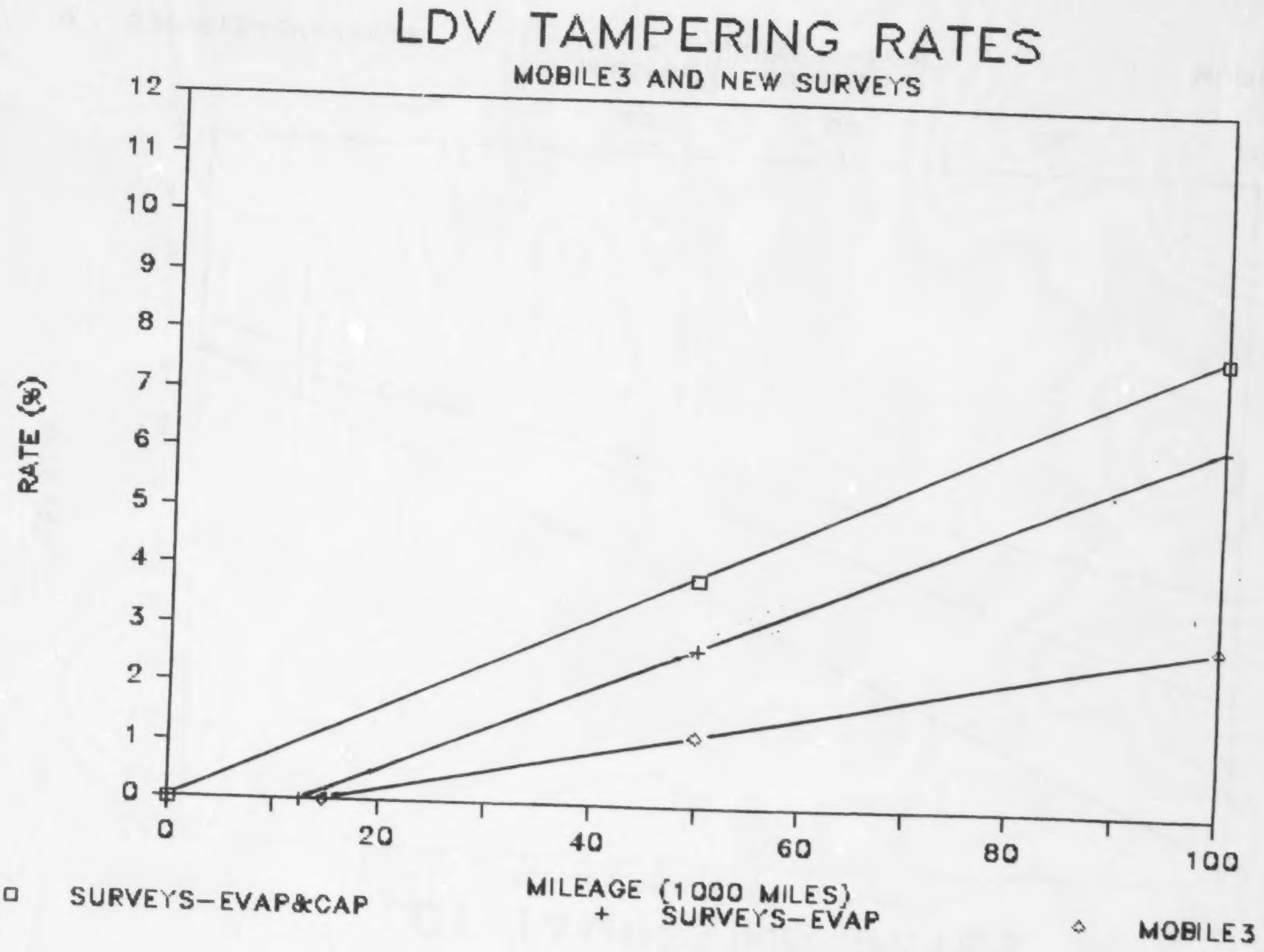
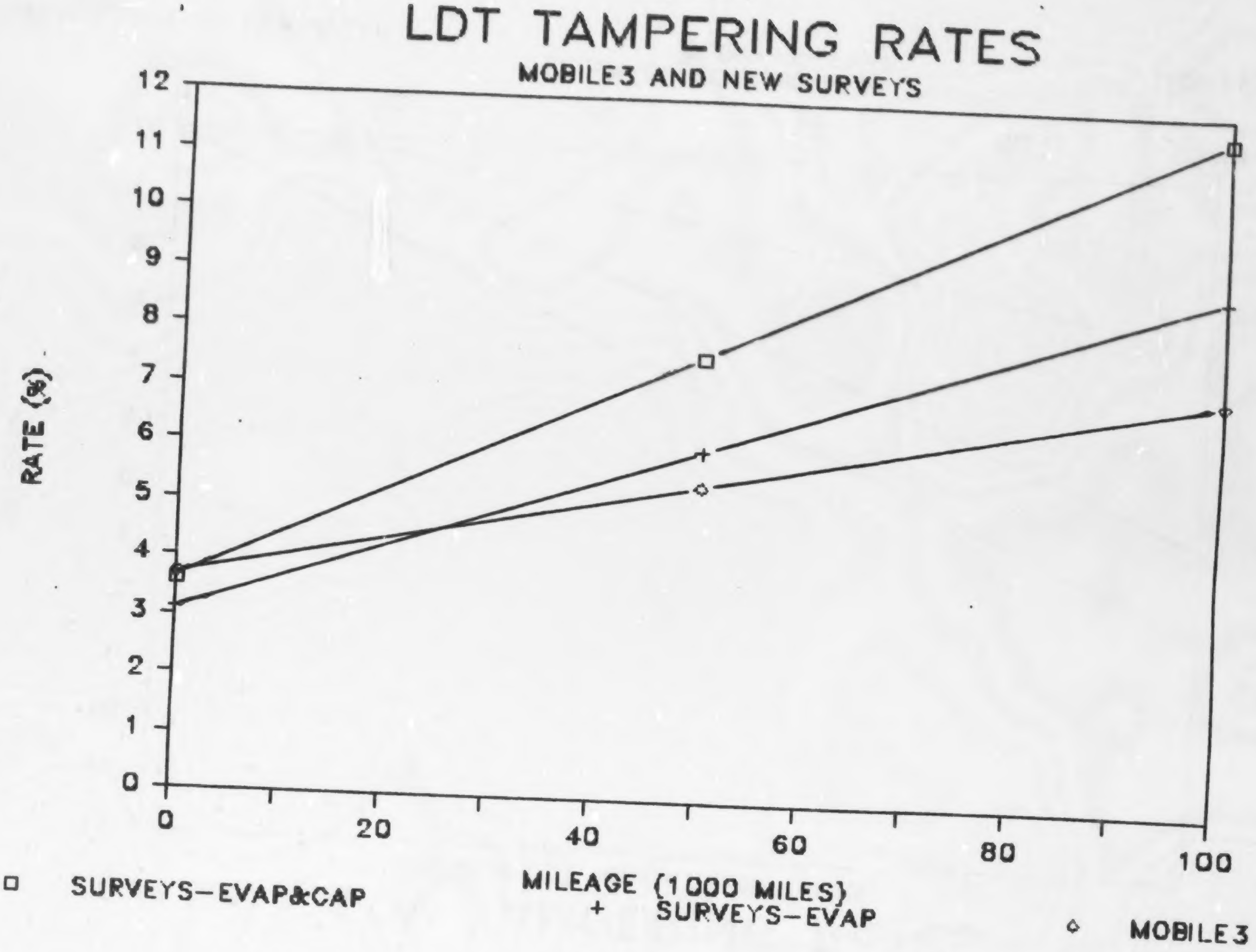

LDV TAMPERING RATES
MOBILE3 AND NEW SURVEYS
RATE (%)
0
1
2
3
4
5
6
7
8
9
10
11
12
0
20
40
60
80
100
MILEAGE (1000 MILES)
□ SURVEYS—EVAP&CAP
+ SURVEYS—EVAP
◇ MOBILE3

Figure 2-9


LDT TAMPERING RATES
MOBILE3 AND NEW SURVEYS
RATE (%)
0
1
2
3
4
5
6
7
8
9
10
11
12
0
20
40
60
80
100
MILEAGE (1000 MILES)
□ SURVEYS–EVAP&CAP
+ SURVEYS–EVAP
◇ MOBILE3

emissions would be uncontrolled. However, because the tampering survey does not make this distinction, a better estimate is not available at this time.

The uncontrolled evaporative emission rates used to quantify the tampering effects are based on SHED testing of vehicles with removed canisters and/or fuel caps. These are summarized in Table 2-17, which also shows the increase with in-use fuel RVP. Several assumptions that were made in deriving these emission rates are described below.

First, with respect to diurnal losses, the effect of fuel cap removal is assumed to be the same as canister removal for both carbureted and fuel-injected vehicles, since diurnal emissions result entirely from the fuel tank. Also, diurnal emissions from fuel-injected vehicles with either missing gas caps or canisters is assumed to be the same as those from uncontrolled carbureted vehicles (for which more data exist). Again, diurnal emissions occur entirely from the fuel tank where the two technologies do not differ. Also, the fuel tank volumes of the two vehicle types do not generally differ.

Second, with respect to hot-soak emissions from fuel-injected vehicles, fuel cap removal is assumed to result in completely uncontrolled hot-soak emissions. A properly assembled fuel injector should emit little, if any, during a hot soak, leaving the fuel tank as the primary source of emissions. Limited data on three fuel-injected vehicles confirm this. Hot-soak emissions using Indolene with the gas cap removed and those with the canister removed were essentially identical at just over 4 grams/test, where controlled emissions were below one gram/test.[48] Emissions using commercial fuel without a canister were only slightly higher than those without a gas cap. Thus, this assumption appears to be valid for fuel-injected vehicles. However, for carbureted vehicles, the increase in hot-soak emissions due to fuel cap removal is expected to be less than totally uncontrolled hot-soak emissions because the carburetor bowl contributes to, and probably is the major source of, hot-soak losses from these vehicles. Since data are not available to precisely predict the degree to which hot-soak emissions from carbureted vehicles would increase with fuel cap removal, it will be assumed that the carburetor bowl dominates and that hot-soak emissions do not increase. Thus, the values presented in Table 2-17 for hot-soak emissions from carbureted vehicles with missing fuel caps are the same as those for non-tampered carbureted vehicles (i.e., 2.32 and 3.84 g/test for 9.0- and 11.5-psi RVPs, respectively, as shown in Table 2-13).

As explained in Appendix 2-B, the tampering offsets used in this analysis were calculated by subtracting the average non-tampered vehicle emissions shown in Table 2-13 from the

Table 2-17

Uncontrolled Evaporative Emissions (g/test) from Tampered Vehicles vs. RVP*

			Canister Disconnects				Fuel Cap Removal			
			--9.0 psi--		-11.5 psi**-		--9.0 psi--		-11.5 psi**-	
Vehicle Type	Model Year	Fuel System	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.
LDV	pre-71	All	14.67	26.08	22.45	47.99	14.67	26.08	22.45	47.99
and	71	All	14.67	26.08	22.45	47.99	10.91	26.08	16.15	47.99
LDT$_1$	72-77	All	14.67	20.90	22.45	35.45	10.91	20.90	8.98	35.45
	78-80	All	13.29	16.32	18.50	25.11	2.32	16.32	3.79	25.11
	81+	Carb	10.36	14.95	17.47	25.71	2.32	14.95	3.84	25.71
		Finj	4.93	14.95	11.59	25.71	4.93	14.95	11.59	25.71
LDT$_2$	pre-79	All	18.08	42.33	27.66	77.89	18.08	42.33	27.66	77.89
	79+	Same as LDV, LDT$_1$								
HDV	pre-85	All	18.08	42.33	27.66	77.89	18.08	42.33	27.66	77.89
	85+		14.67	26.08	23.31	39.87	3.69	26.08	6.11	39.87

---

* Figures presented are for low altitudes; high-altitude correction factors are as follows: 1) LDV -- pre-1977 = 1.3, 1977 = 1.0, 1978-81 = 2.59, 1982-83 =1.3, 1984+ = 1.0; 2) LDT$_1$, LDT$_2$ and HDV -- all model years = 1.3.

** Values for RVPs between 9.0 and 11.5 psi can be calculated via linear interpolation.

uncontrolled emission levels in Table 2-17. These offsets at various RVPs were then incorporated into the EF runs at the tampering incidence rates developed from the survey data previously discussed. These offsets represent extreme increases in evaporative emissions, reaching levels of 10-20 grams/test for 11.5 RVP fuel. (Tampering offsets are shown in Appendix 2-B for light-duty and heavy-duty vehicles in Tables 2-B-6 and 2-B-7, respectively.)

5. Summary

Based on the above discussions, motor vehicle evaporative emissions can be divided into several different categories. The first consists of emissions from properly-designed and operated vehicles assumed to emit at the standard; therefore, none of the control strategies (to be detailed in the last section of this chapter) will reduce this portion. However, the four probable components of current excess motor vehicle emissions will be addressed in the remainder of this study.

The first -- insufficient design of the purge system -- could be addressed via changes to the certification test procedure. The excess RVP effect could theoretically be reduced or eliminated through the reduction of in-use fuel RVP and/or the revision of certification fuel specifications. The effects of the remaining two sources of excess evaporative losses (i.e., malmaintenance/defects and tampering) probably cannot be totally eliminated, but could be significantly reduced if in-use RVP were controlled to lower levels or an effective inspection and maintenance program for evaporative systems could be developed and implemented.

The extent to which each of these five sources contribute to total motor vehicle evaporative losses -- and to total non-methane hydrocarbon (NMHC) inventories -- will be explained in Chapter 5. There, future total NMHC inventories will be broken down into stationary source emissions (separated into bulk storage, Stage I, refueling, and other) and motor vehicle losses (divided into exhaust HC and the five components of evaporative HC losses). Results are presented graphically in Figure 5-1 of Chapter 5.

D. Effect of RVP on Exhaust Emissions

EPA's EF program includes tests for exhaust emissions as well as evaporative emissions. Prior to November of 1983, when testing was only performed using Indolene, the effect of RVP on in-use emissions was not known. Between October 1983 and July 1984, RVP appeared to have little effect on exhaust emissions.[49] However, since July 1984 (when the test sequence was improved), a significant effect has been seen, particularly that lowering RVP lowers exhaust emissions of HC and CO; no significant reduction in NOx emissions with lower volatility fuels has been noted. The lack of an effect prior to July 1984 is presumed to be due to the extra purging of the in-use canister during the evaluation on Indolene, in which the HFET and various short tests were conducted.

Figures 2-10 through 2-15 show the trend toward higher exhaust emissions with higher volatility fuel for each of the three pollutants. This effect is seen with open-loop carbureted, closed-loop carbureted, and fuel-injected vehicles. The data in these figures consist of all those cars tested between July 1984 and July 1985, in which the commercial fuel was tested first and the prep cycle was a full LA-4.*

Tables 2-18 through 2-22 present the results of statistical analyses to determine if the trends noted in the above figures are significant. Table 2-18 shows the results obtained from assuming a simple binomial model. If there exists no relationship between exhaust emissions and fuel volatility, then the number of vehicles showing higher emissions with a higher RVP fuel should be approximately one half of the total number of vehicles. The standardized value determined (α) is a measure of the likelihood that a given number of vehicles would have higher emissions at a higher RVP if there is no relationship between the two (i.e., if randomness is assumed). As Table 2-19 shows, α is less than 0.05 for all but one of the HC and CO cases, which indicates that an RVP/exhaust emissions relationship probably exists (i.e., the results are not randomized).

Tables 2-19 through 2-22 show the results of performing analyses of variance using the following model:

Exhaust Emissions (VEH,RVP) = $\mu + A_{VEH} + A_{RVP}$, where

μ = overall mean for all vehicles at all RVPs
A_{VEH} = average deviation from the mean for a given vehicle
A_{RVP} = average deviation from the mean for a given RVP

Should the effect of RVP not be significant, then the value of A_{RVP} will be equal to zero for each RVP. This is indicated by the F-statistic, which is a measure of the relative amount of variance in the data explained by the given factor (in this case RVP). The vehicle-related variability was also included in this analysis so that the effect of fuel volatility could be more clearly identified The tables indicate that the F-statistic is greater than F-95% in all of the HC and CO cases, which indicates that RVP is significantly related to exhaust HC and CO (see footnotes on tables).

---

* Because the analysis on the effect of RVP on exhaust emissions was conducted after the analysis on evaporative emissions, more vehicles were able to be included (i.e., the exhaust data were "frozen" in July 1985, while evaporative data were examined only through April 1985).

Figure 2-10

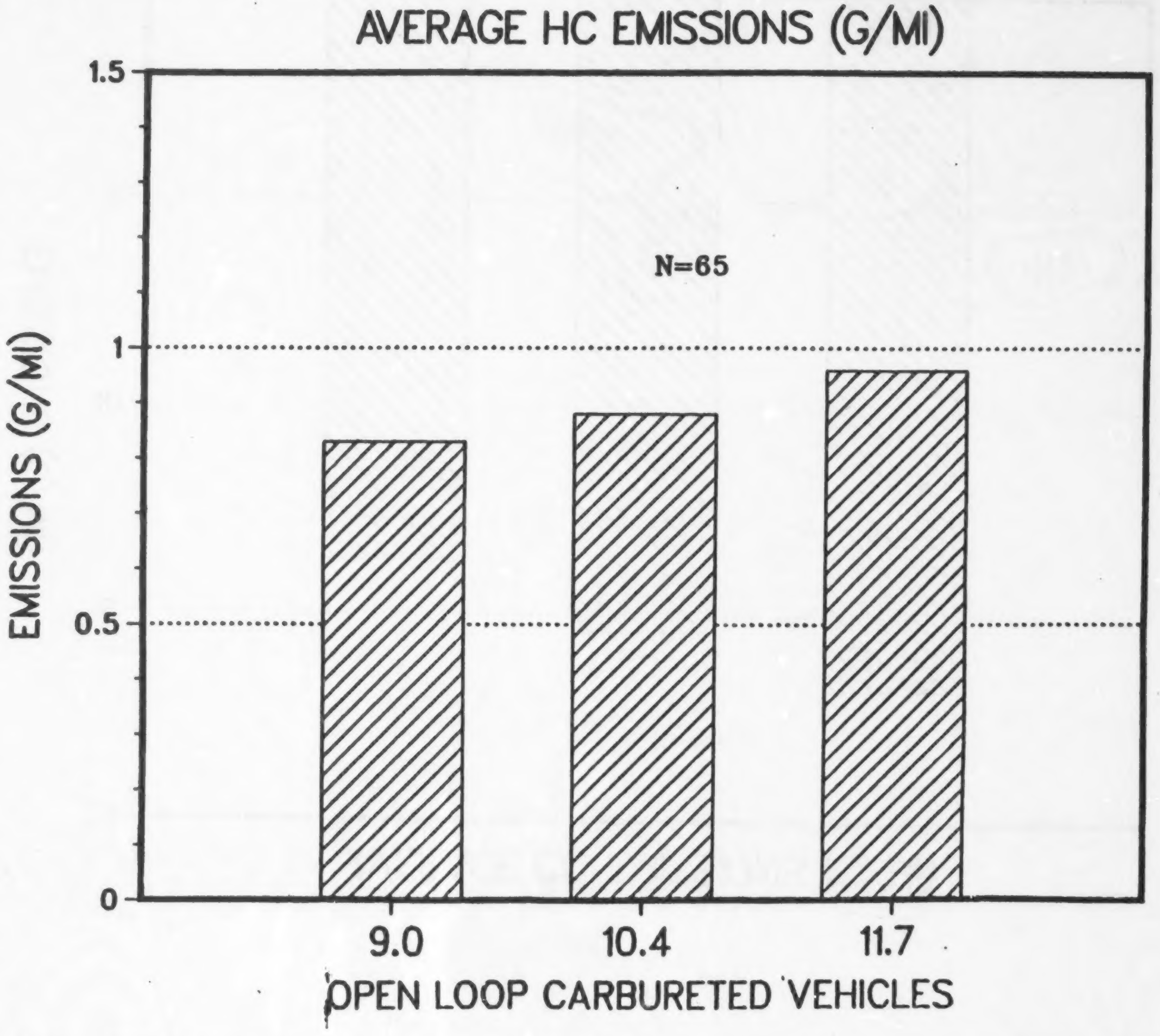

AVERAGE HC EMISSIONS (G/MI)
N=65
EMISSIONS (G/MI)
1.5
1
0.5
0
9.0
10.4
11.7
OPEN LOOP CARBURETED VEHICLES

Figure 2-11

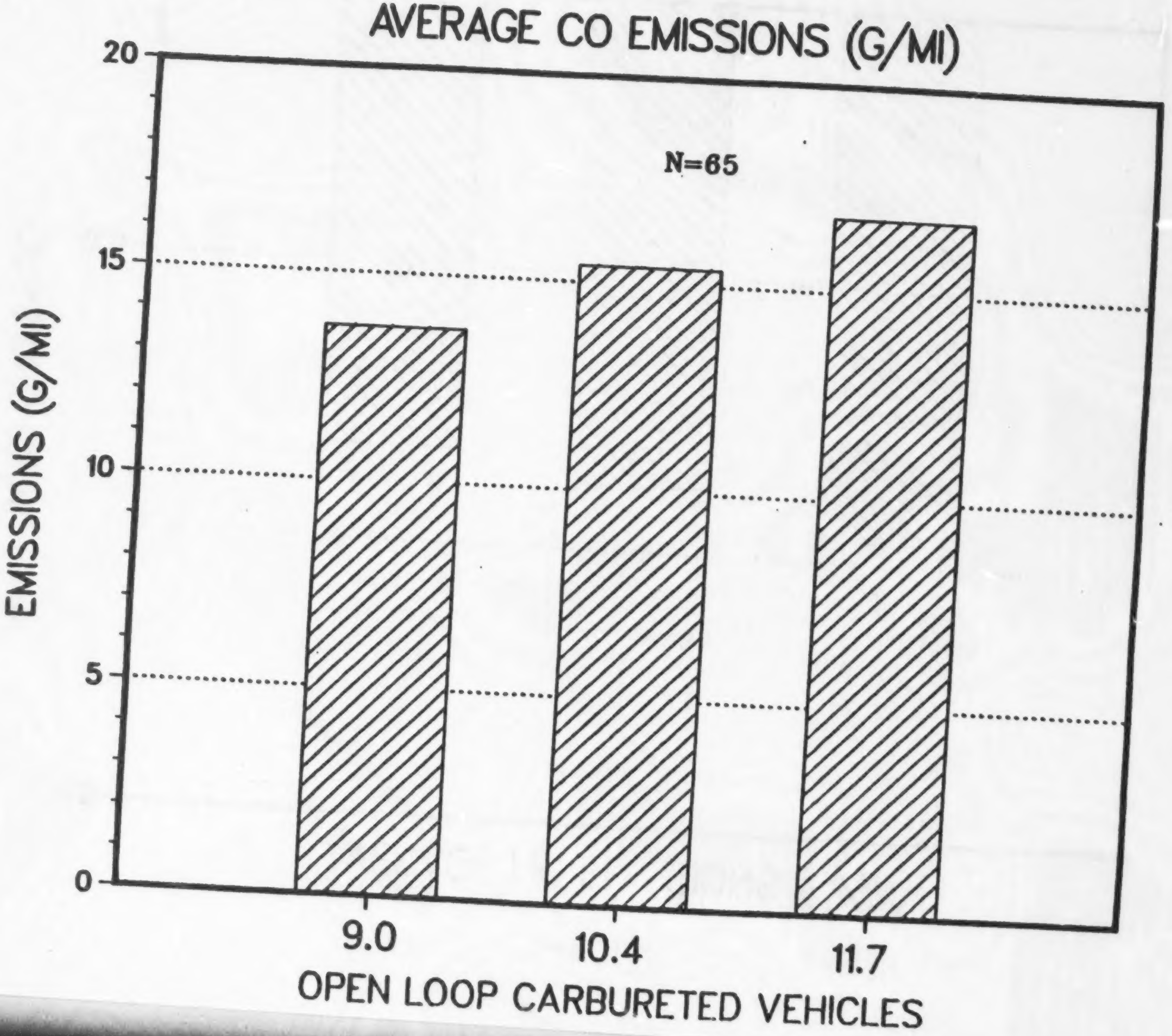

AVERAGE CO EMISSIONS (G/MI)
N=65
EMISSIONS (G/MI)
20
15
10
5
0
9.0
10.4
11.7
OPEN LOOP CARBURETED VEHICLES

Figure 2-12

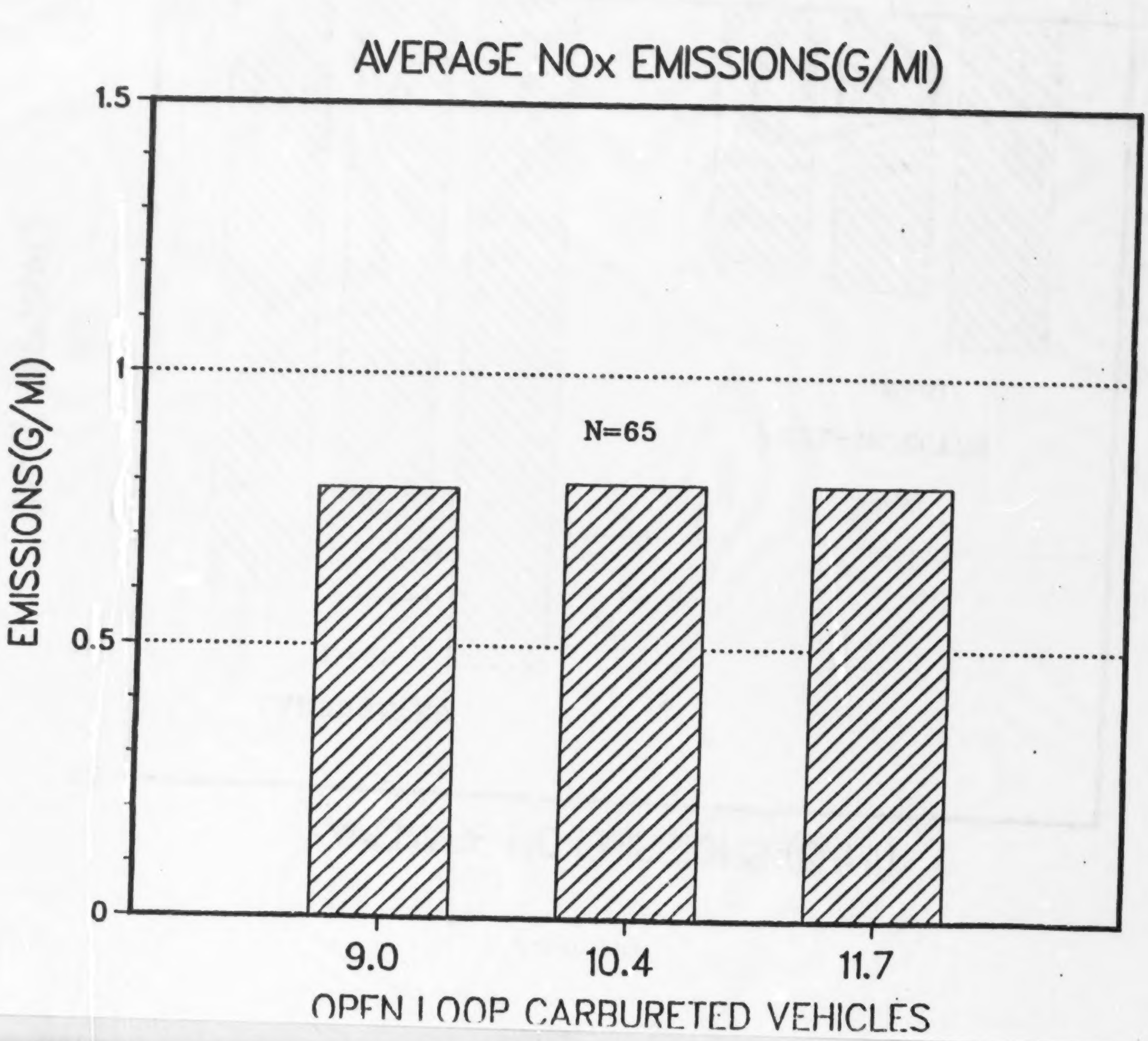

AVERAGE NOx EMISSIONS(G/MI)
EMISSIONS(G/MI)
1.5
1
0.5
0
N=65
9.0
10.4
11.7
OPEN LOOP CARBURETED VEHICLES

Figure 2-13

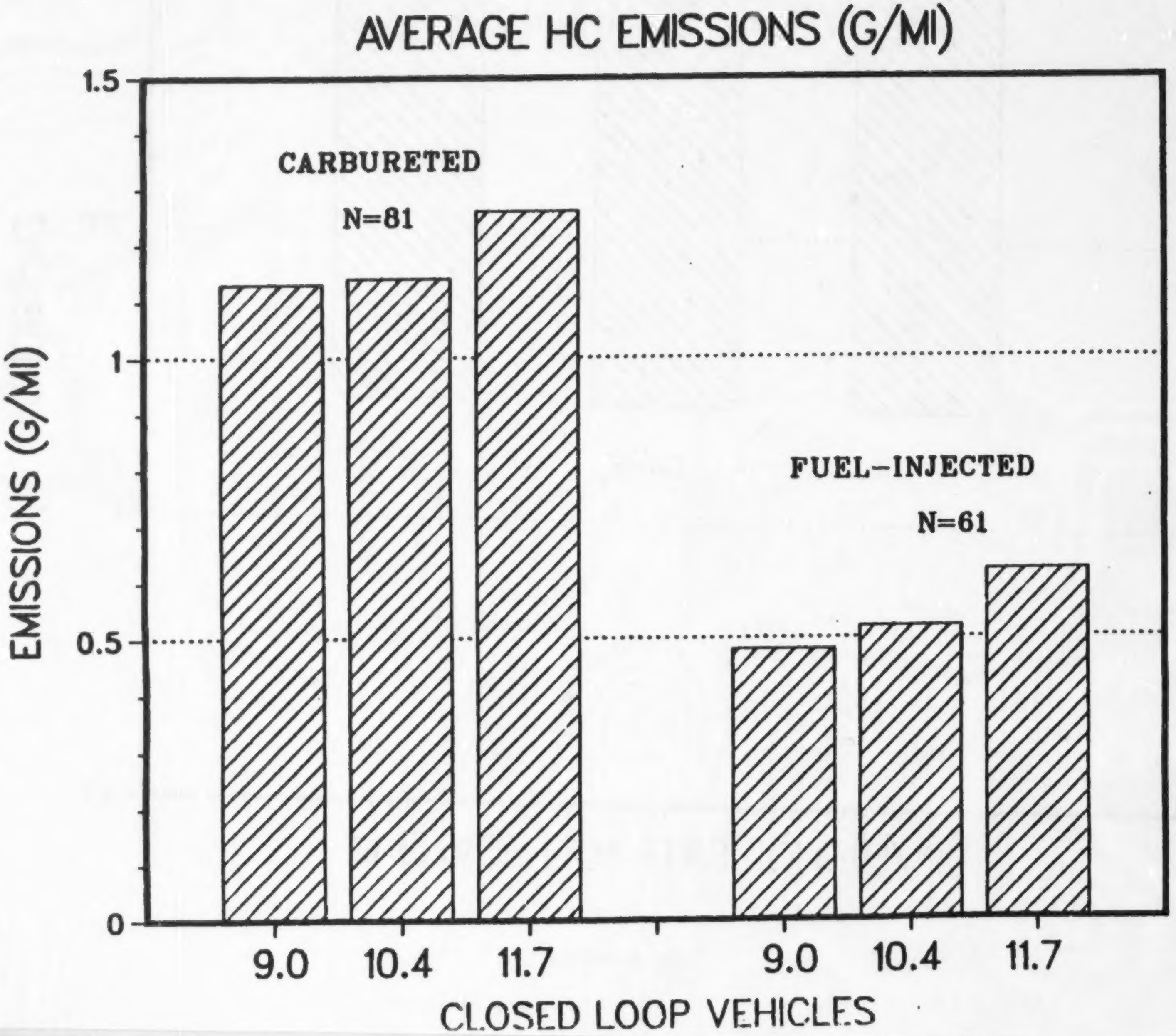

AVERAGE HC EMISSIONS (G/MI)
EMISSIONS (G/MI)
1.5
1
0.5
0
CARBURETED
N=81
FUEL-INJECTED
N=61
9.0
10.4
11.7
9.0
10.4
11.7
CLOSED LOOP VEHICLES

Figure 2-14

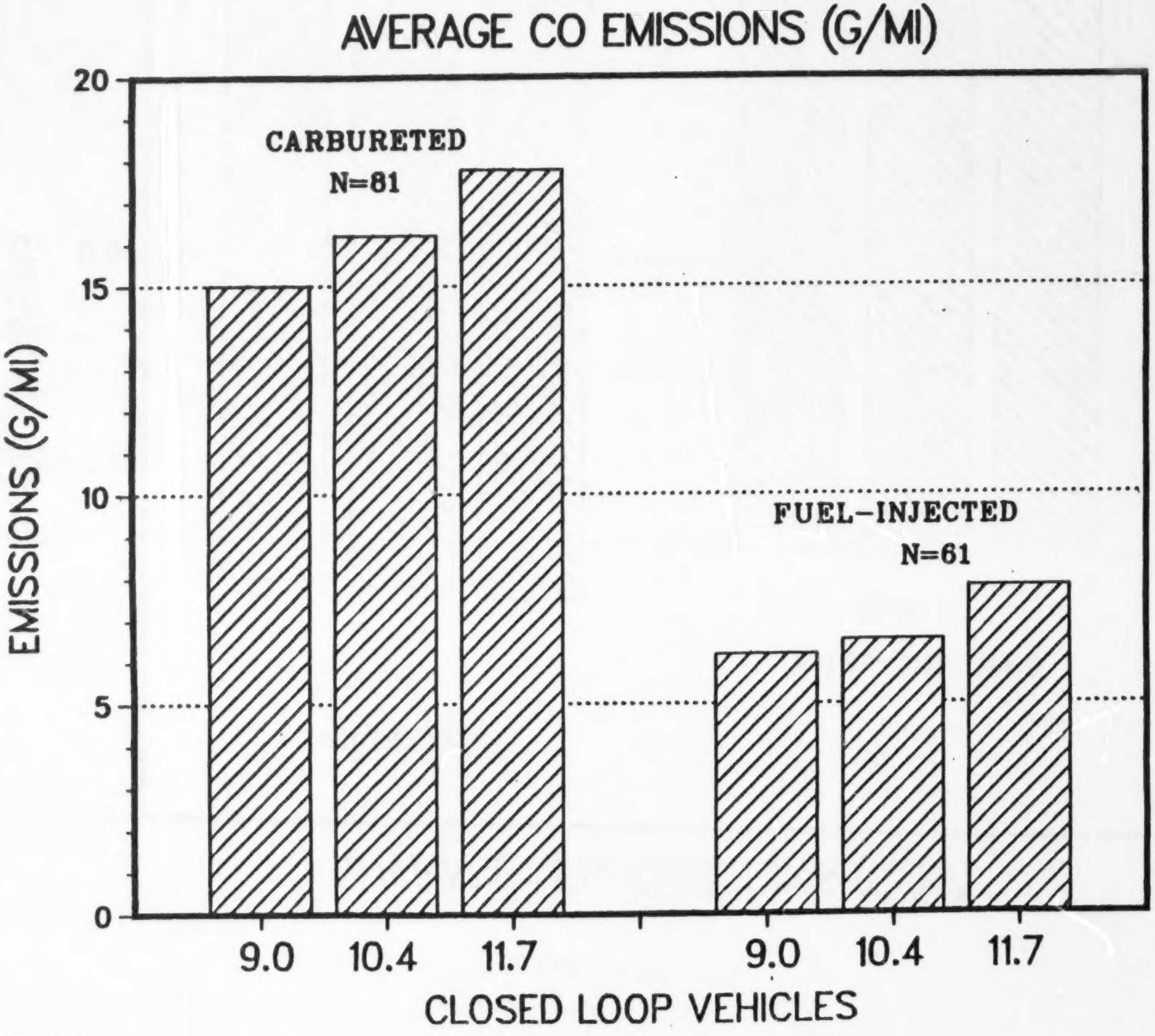

AVERAGE CO EMISSIONS (G/MI)
EMISSIONS (G/MI)
20
15
10
5
0
CARBURETED
N=81
FUEL-INJECTED
N=61
9.0
10.4
11.7
9.0
10.4
11.7
CLOSED LOOP VEHICLES

Figure 2-15

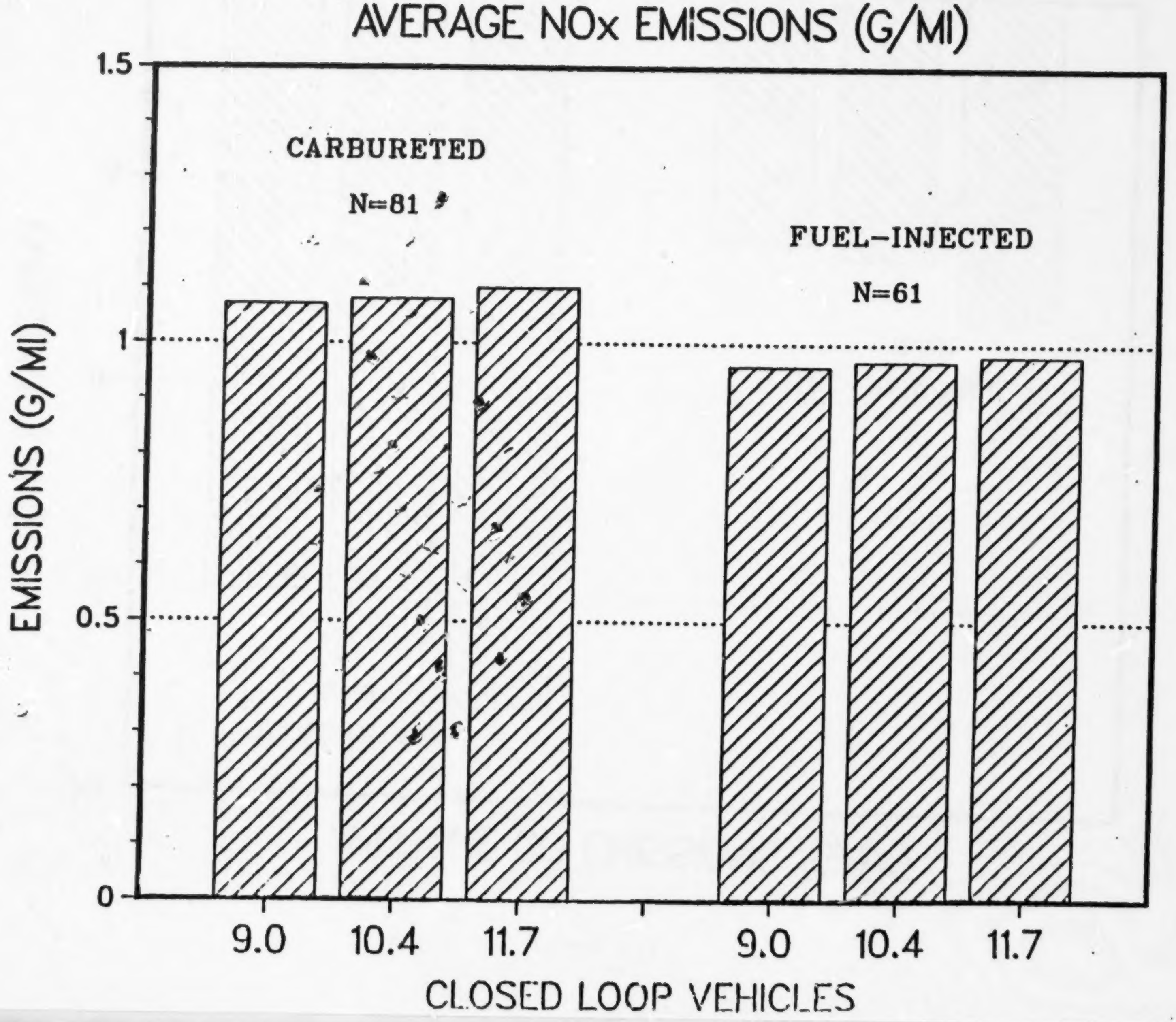

AVERAGE NOx EMISSIONS (G/MI)
EMISSIONS (G/MI)
1.5
1
0.5
0
CARBURETED
N=81
FUEL-INJECTED
N=61
9.0
10.4
11.7
9.0
10.4
11.7
CLOSED LOOP VEHICLES

Table 2-18

Vehicles Showing Higher Exhaust Emissions with Higher RVP Fuels

	RVP(psi) High/Low	CARBURETED VEHICLES Open-Loop Number	Open-Loop α*	Closed-Loop Number	Closed-Loop α*	Combined Number	Combined α*
HC	10.4/9.0	53 out of 65	.0000	49 out of 81	.0294	102 out of 146	.0000
	11.7/10.4	44 out of 65	.0022	69 out of 81	.0000	113 out of 146	.0000
	11.7/9.0	54 out of 65	.0000	68 out of 81	.0000	122 out of 146	.0000
CO	10.4/9.0	48 out of 65	.0000	59 out of 81	.0000	107 out of 146	.0000
	11.7/10.4	38 out of 65	.0869	65 out of 81	.0000	103 out of 146	.0000
	11.7/9.0	52 out of 65	.0000	71 out of 81	.0000	123 out of 146	.0000
NOx	10.4/9.0	26 out of 65	.5537	44 out of 81	.2177	70 out of 146	.8085
	11.7/10.4	34 out of 65	.3557	44 out of 81	.2177	78 out of 146	.2033
	11.7/9.0	34 out of 65	.3557	50 out of 81	.0174	84 out of 146	.0344

		FUEL INJECTED (All Closed-Loop) Number	α*	ALL VEHICLES Number	α*
HC	10.4/9.0	42 out of 61	.0016	144 out of 207	.0000
	11.7/10.4	50 out of 61	.0000	163 out of 207	.0000
	11.7/9.0	54 out of 61	.0000	176 out of 207	.0000
CO	10.4/9.0	40 out of 61	.0075	147 out of 207	.0000
	11.7/10.4	40 out of 61	.0075	143 out of 207	.0000
	11.7/9.0	44 out of 61	.0003	167 out of 207	.0000
NOx	10.4/9.0	37 out of 61	.0485	107 out of 207	.3121
	11.7/10.4	31 out of 61	.4483	109 out of 207	.2236
	11.7/9.0	38 out of 61	.0274	122 out of 207	.0051

---

* α = A measure of the likelihood that this many vehicles would show higher exhaust emissions at a higher RVP if there was no real relationship between the two (i.e., a higher value indicates a higher likelihood that this occurrence is random). Values above .05 indicate that the occurrence can be considered random at a 95-percent confidence level. Values below .05 indicate that the occurrence is not random and that there is a statistically significant relationship between exhaust emissions and fuel RVP.

Table 2-19

Analysis of Variance - Exhaust RVP Effect
(All Vehicles)

Exhaust HC

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	2.0401	1.0201	37.557	3.00	2.30
VEH	206	883.050	4.2866	160.993	1.00	1.00
ERR	412	10.970	.0266			
TOTAL	620	896.060				

Exhaust CO

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	661.020	330.51	27.626	3.00	2.30
VEH	206	258900.000	1256.8	105.053	1.00	1.00
ERR	412	4828.980	11.964			
TOTAL	620	264490.000				

Exhaust NOx

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	.050497	.025248	1.934	3.00	2.30
VEH	206	257.49	1.2499	95.726	1.00	1.00
ERR	412	5.380	0.013			
TOTAL	620	262.92				

---

* The F-statistic is a measure of the significance of a given factor (here, RVP) in relation to the exhaust emissions. A value larger than the theoretical value (i.e., F 95%) indicates that the RVP of the fuel is significant in relation to exhaust emissions using the given level of significance (i.e., a 95% confidence interval).

Table 2-20

Analysis of Variance - Exhaust RVP Effect
(Carbureted Open-Loop Vehicles)

Exhaust HC

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	.62937	.31469	10.094	3.07	2.35
VEH	64	187.000	2.9219	93.720	1.43	1.32
ERR	128	3.991	0.031			
TOTAL	194	191.620				

Exhaust CO

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	313.180	156.590	13.472	3.07	2.35
VEH	64	77333.000	1208.300	103.952	1.43	1.32
ERR	128	1487.820	11.624			
TOTAL	194	79134.000				

Exhaust NOx

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	.0051764	.0025882	.371	3.07	2.35
VEH	64	59.598	.93121	133.503	1.43	1.32
ERR	128	.893	.007			
TOTAL	194	60.496				

---

* The F-statistic is a measure of the significance of a given factor (here, RVP) in relation to the exhaust emissions. A value larger than the theoretical value (i.e., F 95%) indicates that the RVP of the fuel is significant in relation to exhaust emissions using the given level of significance (i.e., a 95% confidence interval).

Table 2-21

Analysis of Variance - Exhaust RVP Effect
(Carbureted Closed-Loop Vehicles)

Exhaust HC

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	.86908	.43454	13.604	3.00	2.30
VEH	80	622.70	7.7838	243.676	1.29	1.21
ERR	160	5.111	0.032			
TOTAL	242	628.68				

Exhaust CO

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	307.940	153.970	9.653	3.00	2.30
VEH	80	161460.000	2018.200	126.530	1.29	1.21
ERR	160	2552.060	15.951			
TOTAL	242	164320.000				

Exhaust NOx

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	.046258	.023129	1.342	3.00	2.30
VEH	80	111.960	1.3995	81.206	1.29	1.21
ERR	160	2.757	.017			
TOTAL	242	114.760				

---

* The F-statistic is a measure of the significance of a given factor (here, RVP) in relation to the exhaust emissions. A value larger than the theoretical value (i.e., F 95%) indicates that the RVP of the fuel is significant in relation to exhaust emissions using the given level of significance (i.e., a 95% confidence interval).

Table 2-22

Analysis of Variance - Exhaust RVP Effect
(Fuel-Injected Vehicles)

Exhaust HC

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	.59899	.29950	19.802	3.07	2.35
VEH	60	30.841	.51401	33.984	1.43	1.32
ERR	120	1.815	.015			
TOTAL	182	33.255				

Exhaust CO

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	86.789	43.395	6.163	3.07	2.35
VEH	60	9470.300	157.84	22.418	1.43	1.32
ERR	120	844.911	7.041			
TOTAL	182	10402.000				

Exhaust NOx

Source	DF	SS	MSE	F-stat*	F 95%	F 90%
RVP	2	.010244	.0051219	.357	3.07	2.35
VEH	60	77.208	1.2868	89.685	1.43	1.32
ERR	120	1.722	.014			
TOTAL	182	78.940				

---

* The F-statistic is a measure of the significance of a given factor (here, RVP) in relation to the exhaust emissions. A value larger than the theoretical value (i.e., F 95%) indicates that the RVP of the fuel is significant in relation to exhaust emissions using the given level of significance (i.e., a 95% confidence interval).

The above analyses show that for each technology class, the trends in HC and CO emissions versus RVP are significant, whereas the trend in NOx emissions versus RVP is not.

As described earlier with respect to evaporative emissions, these test data directly apply only to vehicles designed for 9-psi RVP fuel and operated on fuels of various RVPs. They do not apply to vehicles designed for and tested on higher RVP fuels. Thus, the data are directly applicable only to the situation where vehicle designs are not changing, but in-use RVP is being reduced (i.e., pre-1990 vehicles). The question that remains is what happens to exhaust emissions when vehicles are redesigned for some higher RVP and then operated on that fuel.

Two extremes appear possible. One, the exhaust emission effect is completely related to in-use fuel RVP and redesign for that RVP will not reduce the exhaust emission effect. Two, vehicles currently exhibit lower emissions on Indolene because they are designed using Indolene and, therefore, optimizing them for any other RVP will result in the same low emissions when operated on that fuel (i.e., the exhaust effect will be eliminated if design RVP equals in-use RVP). The fact that the earlier EF testing did not show an RVP-related exhaust emission effect argues for the latter. The only difference between the two sets of EF testing was the evaporative emission test procedure and the sequence of fuels. Since no hysteresis is known to be present with respect to the effect of fuel RVP on exhaust emissions outside of the purging of the evaporative control canister, all of the changes between the two sets of testing appear to be related to evaporative emissions. Since the earlier test sequence (which mitigated the impact of higher RVPs) eliminated the RVP effect on exhaust emissions, it would appear reasonable to conclude that redesigning the vehicle's evaporative and exhaust emission control systems for a higher RVP would eliminate the exhaust effect, as well.

Thus, the exhaust emission effect is assumed to be eliminated via any of the long-term strategies for post-1989 model year vehicles, when design RVP will be equal to in-use RVP. Under the short-term strategies, where in-use RVP would be less than certification fuel RVP, the exhaust effect is also assumed to be eliminated (i.e., the car would be designed to handle any RVP less than or equal to certification RVP).

For pre-1990 vehicles that are operated on 9.0-psi fuel, this exhaust effect is also assumed to be eliminated. However, when these Indolene-designed vehicles are operated on RVPs greater than 9.0 psi, the exhaust effect will be dependent on the in-use RVP. (Adjustment of MOBILE3 exhaust emission factors, based on 11.5 RVP fuel, for various control scenarios will be discussed in Chapter 5.)

VI. Summary of Evaporative Emissions Problem and Development of Possible Control Scenarios

1. Review

At this point, it may be helpful to review the major topics discussed in this chapter. First, the current ozone non-attainment problem is quite widespread and is expected to continue without further reductions in hydrocarbon emissions. (Of the 54 current non-attainment areas, 35 have requested extensions to 1987.) The necessary HC reductions would appear to be most valuable in the summer months because roughly 90 percent of all ozone violations occur between June and September (inclusive).

Evaporative HC emissions from motor vehicles and stationary sources (gasoline storage and distribution) represent a significant portion of those emissions contributing to the ozone problem. Motor vehicle evaporative losses -- the primary focus of this study -- can be affected by several factors, primarily the vehicle's evaporative control system design and the volatility of the fuel being used in the vehicle. There are some indications that the use of alcohol blends could be another factor affecting evaporative emissions. However, based on the review presented in Section IV of this chapter, alcohol blends only affect evaporative emissions during their use (i.e., alcohol blends do not appear to permanently deactivate the charcoal). At similar volatilities, alcohol blends appear to yield similar evaporative emissions when compared to gasoline. Thus, the analyses conducted in the rest of this study will treat alcohol blends in the same manner as gasoline.

Fuel survey data indicate that some current commercial gasolines are significantly more volatile than that for which vehicle evaporative control systems are designed (i.e., EPA's certification test fuel, as defined in the *Code of Federal Regulations*). This trend of increasing commercial fuel volatility has been occurring over the past two decades and there is no evidence that the trend will not continue in the future. Fuel volatility can be assessed using various fuel parameters, with RVP and percent of fuel evaporated at 160°F chosen (for purposes of this analysis) to be most pertinent to diurnal and hot-soak losses from motor vehicles. Of these two parameters, RVP will be the primary focus due to indications of its greater significance and the existence of more data defining its relationship to evaporative emission levels. However, the impact of $\%_{160}$ on evaporative losses (particularly hot-soak) will continue to be examined in future work.

The RVP of current certification test fuel averages 9.0 psi, which is representative of the early 1970's when the specifications were first developed. Results of EPA's ongoing emission factor test program show that vehicles operating on commercial fuels with RVPs greater than 9.0 psi (for which they were designed) have evaporative losses that greatly exceed the current standard of 2 grams/test, and that this excess is dependent upon the RVP of the fuel being tested. Using in-use test data, the evaporative excess was attributed to the RVP effect, malmaintenance and equipment defects, and tampering (the latter two also being dependent on RVP). In addition, because vehicles also have difficulty meeting the evaporative standard even on 9.0-psi Indolene, some of the excess emissions are attributed to insufficient design of the purge system.

There are several approaches that can be taken to reduce or eliminate these excess evaporative emissions from motor vehicles. One is to control the volatility of in-use (or commercial) fuel to a level equal to that for which the vehicles' evaporative control systems are designed. Another option is to change new vehicle design by revising certification fuel specifications and test procedure; these revisions would force manufacturers to increase the size of the evaporative canister in order to accommodate higher emissions from the more volatile commercial fuels, and to improve the purge system to enable the vehicle to pass certification tests while starting with a saturated canister (to be discussed in more detail in Chapter 3). The retrofitting of in-use vehicles with larger canisters or additional smaller ones in parallel with existing systems is another approach. Though the technical feasibility of this option has not been fully assessed, it would most likely be very costly and of questionable effectiveness. Therefore, retrofit will not be considered further in this report. Rather, the options involving changes to in-use and certification fuel volatilities and test procedure will provide the basis for development of the evaporative HC control strategies to be examined in the remainder of this report.

2. Development of Control Strategies

As certification tests are intended to represent in-use operating conditions, the long-term control strategy is to have certification fuel RVP equal to that of typical in-use gasoline. This can be accomplished by controlling in-use fuel volatility, by revising certification fuel specifications, or through a combination of the two. One remaining question concerns the volatility level at which commercial and certification fuels should be matched. The long-term control options to be considered in this report are presented in Table 2-23. As shown, this analysis examines RVPs at 0.5-psi increments between 9.0 and 11.5 psi (inclusive). In addition,

Table 2-23

Long-Term RVP Control Scenarios

Scenario	In-Use RVP (psi)*	Certification RVP (psi)**
1	11.5 (baseline)	11.5
2	11.0	11.0
3	10.5	10.5
4	10.0	10.0
5	9.5	9.5
6	9.0	9.0 (baseline)

---

* In-use RVP control is assumed to be implemented in 1988.

** Certification RVP and test procedure are assumed to be revised with the 1990 model year.

all strategies that involve a change to certification fuel RVP also assume a change in certification test procedure to correct design problems such as inadequate purge.

As indicated in Table 2-23, a fuel volatility representative of ASTM's "Class C" cities was chosen as the baseline commercial (in-use) RVP for two basic reasons: 1) the conditions of EPA's test procedure most closely resemble the summer climate of these areas, and 2) a majority of the current non-attainment areas are designated as Class C in the summer. Although fuel survey data indicate that the current average RVP in Class C cities is just below 11 psi, RVP is expected to continue its historical upward trend and the ASTM Class C RVP limit of 11.5 psi is assumed to be representative of uncontrolled levels in the late 1980's and early 1990's.

The earliest reasonable implementation dates estimated for the vehicle-related and fuel-related control measures differ from each other and are based on the following assumptions. Possible control measures that affect vehicle design -- revisions to certification fuel and test procedure -- are assumed to be first implementable with the 1990 model year. This is based on the assumption that a Final Rulemaking (FRM) establishing these controls would be published no earlier than late 1986, which already falls into the 1987 model year. Allowing 2-3 years for the redesign of vehicles, revised certification fuel and test procedure could probably be implemented starting with the 1990 model year. On the other hand, less leadtime is estimated to be necessary on the fuel-related side. Modifications to in-use fuel volatility can be accomplished with changes in refinery operating parameters as opposed to changes in equipment design, if desired. (These refinery modifications are discussed in more detail in Chapter 4.) Based on this assumption, the implementation date assumed for in-use fuel volatility control is 1988. Again, this assumes that the FRM would be published in late 1986.

Because changes in certification fuel or test procedure affect only the design of new vehicles, it takes some time before the in-use fleet has turned over and the full impact of larger canisters and improved purge cycle are realized. However, any modification to in-use fuel volatility has an immediate effect on evaporative emissions from the entire fleet. In addition to affecting motor vehicle emissions, in-use fuel volatility has an impact on HC vapors emitted during gasoline storage and distribution (bulk terminals, refueling, etc.). Therefore, a viable short-term option is to control in-use fuel volatility to levels below the certification specification, and then eventually allow in-use RVP to increase to the long-term certification RVP level after a certain period of time. The various RVP scenarios examined under this short-term approach are shown in Table 2-24. Several time periods for this additional control were evaluated

Table 2-24

Short-Term RVP Control Scenarios

Scenario	In-Use RVP (psi)*	Long-Term Certification RVP (psi)**
1	9.0	9.5
2	9.0	10.0
3	9.5	10.0
4	9.0	10.5
5	9.5	10.5
6	10.0	10.5
7	9.0	11.0
8	9.5	11.0
9	10.0	11.0
10	10.5	11.0
11	9.0	11.5
12	9.5	11.5
13	10.0	11.5
14	10.5	11.5
15	11.0	11.5

---

* In-use RVP control is assumed to be implemented in 1988.

** Certification RVP and test procedure assumed to be revised with the 1990 model year.

and will be discussed as results are presented later in the report. As with the long-term scenarios, in-use fuel control is assumed to be implemented in 1988, and vehicle-related controls begin with the 1990 model year.

References (Chapter 2)

1. "1981-1983 Standard Metropolitan Statistical Area (SMSA) Air Quality Data Base for Use in Regulatory Analysis," Memo from Richard G. Rhoads, Director of Monitoring and Data Analysis Division, to Charles Gray, Director of Emission Control Technology Division, February 25, 1985.

2. "Guidance Document for the Correction of Part D SIPS for Non-Attainment Areas," Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, North Carolina, January 27, 1984.

3. "Control Characteristics of Carbon Beds for Gasoline Vapor Emissions", EPA-600/2-77-057, Michael J. Manos and Warren C. Kelly, Scott Environmental Technology, for EPA, ORD, IERL, February 1977.

4. "Combustion Engine Economy, Emissions and Controls, July 9-13, 1984" Engineering Summer Conferences, The University of Michigan College of Engineering.

5. "Hydrocarbon Control for Los Angeles by Reducing Gasoline Volatility," Edwin E. Nelson, Engineering Staff, GM Corp., SAE Paper No. 690087.

6. "Effect of Fuel Front-End and Midrange Volatility on Automobile Emissions," B. H. Eccleston and R.W. Hurn, Bartlesville Energy Research Center, U.S. DOI, Bureau of Mines, Report of Investigations 7707.

7. "Effect of Fuel Composition on Amount and Reactivity of Evaporative Emissions," M.W. Jackson and R.L. Everett, SAE Paper No. 690088, 1969.

8. "Mathematical Models for Prediction of Fuel Tank and Carburetor Evaporation Losses," W.J. Koehl, Jr., Research Dept., Mobil Research and Development Corp., SAE Paper No. 690506, May 1969.

9. "Mathematical Expressions Relating Evaporative Emissions from Motor Vehicles without Evaporative Loss-Control Devices to Gasoline Volatility," William F. Biller, Michael Manoff, Jyotin Sachdev, and William C. Zegal, Scott Research Laboratories, Inc., and David T. Wade, Esso Research Engineering Co., SAE Paper No. 720700, 1972.

10. "Clean Air Act Waiver Application, Section 211(f), Volume 2" E.I. du Pont de Nemours and Company, Inc., July 11, 1984.

References (Chapter 2) Cont'd

11. "Environmental Impacts of Methanol/Gasoline Blends," prepared for Air Pollution Control Association by Tom Cackette and Thomas Austin, February 16, 1984.

12. Letter from Dale F. Pollart, Texaco, Inc., to Richard Wilson, EPA, dated May 13, 1985.

13. "Analysis of Fuel Volatility Characteristics and Evaporative Hydrocarbon Emissions for Alcohol/Gasoline Blends," PLMR-43-83, E.I. du Pont de Nemours and Company, Inc., June 29, 1983.

14. "Standard Specification for Automotive Gasoline, D-439-83," American Society of Tests and Measurements (ASTM).

15. "MVMA National Gasoline Survey, Summer Season, 1984," Motor Vehicle Manufacturers Association, Inc., October 15, 1984.

16. "Motor Gasolines, Summer 1984," Ella Mae Shelton and Cheryl L. Dickson, National Institute for Petroleum and Energy Research (NIPER), for API, February 1985.

17. "Fuel Volatility Trends," Southwest Research Institute, EPA Contract No. 68-03-3192, Work Assignment 4, Task 3, Final Report dated September 28, 1984.

18. "Commentary by General Motors to the EPA on the Appropriateness of Current Emissions Certification Test Fuel Specifications," attachment to internal correspondence from T.M. Fisher, General Motors Corporation, to Charles L. Gray, Jr., EPA, September 3, 1980.

19. Federal Register, January 13, 1985, 50 FR 2615.

20. "Alcohol Outlook," May 1985.

21. "Methanol Demand and Availability," Presented to U.S. EPA Region VI by James L. Snyder, Celanese Chemical Company, Inc., May 21, 1985.

22. "Performance Evaluation of Alcohol-Gasoline Blends in 1980 Model Automobiles, Phase II - Methanol-Gasoline Blends," prepared for DOE by CRC, January 1984.

23. "Physical Properties of Gasoline/Alcohol Blends," Frank N. Cox, U.S DOE, Bartlesville Energy Technology Center, September 1979.

24. "Performance Evaluation of Alcohol-Gasoline Blends in 1980 Model Automobiles, Phase I - Ethanol-Gasoline Blends," prepared for DOE by CRC, July 1982.

References (Chapter 2) Cont'd

25. "Twenty-three Car In-House Oxinol Blend Test Program," EPA Memo from Craig A. Harvey to Charles L. Gray, Jr., ECTD, November 19, 1984.

26. "Evaporative Emissions of Methanol Blend Fueled Vehicles," EPA Technical Report, EPA-AA-TSS-PA-84-5, Craig Harvey, Project Officer, November 1984.

27. "Evaporative Emissions from Vehicles Operating on Methanol/Gasoline Blends," Ken Stamper, SAE Paper No. 801360.

28. "Emissions, Fuel Economy and Driveability Effects of Methanol/Butanol/Gasoline Fuel Blends," Robert L. Furey and Jack B. King, SAE Paper No. 821188.

29. "Impact of Gasohol on Automobile Evaporative and Tailpipe Emissions," Frank M. Black and John M. Lang, SAE Paper NO. 810438.

30. "Evaporative and Exhaust Emissions from Cars Fueled with Gasoline Containing Ethanol or MTBE," Robert L. Furey and Jack B. King, SAE Paper No. 800261.

31. "Gasohol: Technical, Economic or Political Panacea?" Thomas C. Austin and Gary Rubenstein, SAE Paper No. 800891.

32. "Gasohol Test Program," Richard Lawrence, Director, Engineering Operations Division, OMS, U.S. EPA, EPA-AA-TAEB-79-4B, February 1980.

33. "Exhaust and Evaporative Emissions from Alcohol and Ether Fuel Blends," T. M. Naman and J. R. Allsup, SAE Paper No. 800858.

34. "Testing of Three Caltrans Gasohol Fueled Vehicles," California Air Resources Board, May 1980.

35. "Material Compatibility and Durability of Vehicles with Methanol/Gasoline Grade Tertiary Butyl Alcohol Gasoline Blends," David J. Miller, David A. Drake, et al., SAE Paper No. 841383.

36. "Monthly Progress Report No. 3 for the period May 1 through May 31, 1985; Work Assignment No. 29, Contract 68-03-3162, 'Additional Mini-Canister Evaluation,' SwRI Project 03-7338-029," from Lawrence R. Smith, SwRI, to Craig A. Harvey, EPA, June 15, 1985.

References (Chapter 2) Cont'd

37. "The Effect of Methanol on Evaporative Canister Charcoal Capacity," Draft Report, EPA-460/3-84-014, Mary Ann Warner-Selph (SwRI) for EPA, January 1985. (Available from NTIS, No. PB-85-179-752/AS)

38. GM Presentation to EPA-MOD, Washington, D.C., June 12, 1985.

39. "Technical Directive No. 4 to EPA Contract No. 68-03-3230, Effects of RVP and Temperature on Evaporative Emissions of 2-gram, Vehicles," from John Shelton, Project Officer, EPA, to Myron W. Gallogly, President, Automotive Testing Laboratories, March 20, 1985.

40. "Amendment No. 1 to Technical Directive No. 4, Contract 68-03-3230," from John Shelton, Project Officer, EPA, to Myron W. Gallogly, President, Automotive Testing Laboratories, July 18, 1985.

41. "Factors Influencing Vehicle Evaporative Emissions," D.T. Wade, SAE Paper 670126, 1967.

42. "Exhaust and Evaporative Emissions of High Mileage Taxicabs and Passenger Cars," EPA Technical Report, Craig A. Harvey, Project Officer, February 1985.

43. API presentation to EPA on "1984 Evaporative Emissions Research Programs, Gasoline Volatility Assessment Task Force," contractors: NIPER and ATL, 1985.

44. Letter from J.S. Welstand, Chevron Research Division, to Chester J. France, EPA, April 1, 1985.

45. "Motor Vehicle Tampering Survey - 1982," EPA, OMS, FOSD, EPA-330/1-83-001, April 1983.

46. "Motor Vehicle Tampering Survey - 1983," EPA, OMS, FOSD, August 1984 (no report number given).

47. Data in support of "Motor Vehicle Tampering Survey - 1984," EPA, OMS, FOSD, report not yet published.

48. "Report for Third Quarter, FY 85, In-Use Vehicle Testing in Ann Arbor," EPA memorandum from Howard Brasher-Frederick to Charles L. Gray, EPA, OMS, ECTD, July 23, 1985.

References (Chapter 2) Cont'd

49. "Relationship Between Exhaust Emissions and Fuel Volatility," EPA memo from Thomas L. Darlington to Charles L. Gray, EPA, OMS, ECTD, June 24, 1985.

50. "Evaporative HC Emissions for MOBILE3," EPA Technical Report No. EPA-AA-TEB-85-1, U.S. EPA, OAR, ECTD, TEB, August 1984.

Appendix 2-A

Effect of Ambient Temperature Conditions on Evaporative Emissions

As mentioned earlier in Section IV.D. of this chapter, the effect of ambient temperature conditions on evaporative HC emissions is one of the areas still being investigated by EPA. The purpose of this Appendix is twofold. First, available data on evaporative emissions vs. temperature are analyzed and compared to relative emissions predicted via a theoretical emission model. Second, typical summertime temperature and RVP conditions in several of the current ozone non-attainment areas are compared to EPA's standard evaporative test conditions by means of a theoretical diurnal emissions model. Estimates made in this Appendix are offered as a preliminary assessment of the impact of temperature conditions as they differ from those specified as part of the standard evaporative test procedure. These preliminary results have not been incorporated into the emission projections made in this study, as more data and analysis are required before this can be done with confidence.

The first section below reviews available data from a current EPA test program designed to evaluate the impact of temperature on evaporative emissions. The next section relates these measured emissions to relative emission indexes calculated for each test condition using a theoretical diurnal emissions model. Finally, theoretical emissions indexes are calculated for several ozone non-attainment areas using typical summertime (i.e., July) temperature conditions; these indexes provide the basis for a rough comparison of city conditions to standard EPA test conditions.

A. Temperature vs. Emissions Test Program

An EPA-sponsored test program is currently being conducted at the Automotive Test Laboratory (ATL) for the purpose of measuring diurnal and hot-soak losses at various temperatures and gasoline RVPs.[35] The complete test matrix consists of the following:

Parameter	Test Points
Gasoline RVP	9.0, 10.4, 11.7 psi
Diurnal Starting Temp.	60, 68, 75°F
Diurnal Temp. Change	+15, +20, +24, +30 °F
Hot Soak Temp.	70, 82, 95°F

At the time of this analysis, testing of 24 light-duty vehicles certified to the 2-gram standard (i.e., 1981 and later models) -- 14 carbureted, 10 fuel-injected -- had been completed. The first 9 vehicles were tested over the entire matrix listed above; however, in order to include a greater number of vehicles in the program, the other 15 vehicles were tested over only a partial matrix (i.e., two RVPs, two diurnal starting temperatures, and two hot-soak temperatures, instead of three).

Data from fuel-injected and carbureted vehicles were analyzed separately in the following manner:

1) Full-matrix data were separated from data on vehicles tested over only a partial matrix;

2) Emission results (in grams/test) were averaged within each set for each of the temperature/RVP combinations;

3) Emission averages at each condition within each set of data (i.e, full vs. partial matrix) were "normalized" to the standard certification test with 9.0-psi Indolene, starting diurnal temperature of 60°F, diurnal change of +24°F, and hot-soak temperature of 82°F (i.e., the average g/test measurement under these standard conditions was subtracted from all other averages, making the standard value in each set zero);

4) After normalization, the two data sets (full and partial) were combined into one normalized set by arithmetically weighting the emission averages in each set by the number of vehicles tested in each data set (see Table 2-A-1);

5) The average emission factor at 9.0 RVP from the in-use EF test program was then added to each value in the normalized set, so that the g/test associated with the 9.0 RVP (Indolene) test under standard temperature conditions was consistent with the in-use EF results used in the rest of this study (see Table 2-A-2).*

Focusing on the diurnal losses measured under standard test temperatures, the difference between emissions at 9.0 RVP and 11.7 RVP was significantly less in the ATL data than that indicated by the in-use EF results (4.26 versus 7.82 g/test for carbureted vehicles and 1.44 versus 5.23 g/test for fuel-injected vehicles). In fact, before normalization, the ATL emission levels were lower overall than the average in-use results. This is most likely due to the relative condition of the ATL test vehicles, which were somewhat better maintained,

---

* A multiplicative approach could also have been used, wherein the ATL averages would have been normalized to 1.0 at the standard 9.0 RVP test, and then the EF average at 9.0 RVP would have been multiplied by each value in the normalized set.

Table 2-A-1

ATL Diurnal Averages -- Normalized to 9.0 RVP Standard Test

Vehicle Type	RVP (psi)	No. of Vehicles	Starting Temp(°F)	Diurnal Emissions (g/test)			
				+15°F	+20°F	+24°F	+30°F
CARB	9.0	14	60	-0.38	-0.20	0.00	0.60
		5	68	-0.23	0.11	0.62	2.57
		14	75	-0.08	0.65	2.13	7.55
CARB	10.4	10	60	-0.14	0.58	0.96	5.03
		5	68	0.14	1.11	3.13	9.44
		10	75	0.92	4.30	9.69	24.21
CARB	11.7	9	60	0.39	1.74	4.26	12.29
		5	68	0.84	4.41	10.17	22.94
		9	75	6.46	18.48	31.38	64.29
FI	9.0	10	60	-0.24	-0.13	0.00	0.44
		4	68	-0.30	-0.05	0.58	3.38
		10	75	-0.16	0.30	1.25	5.17
FI	10.4	6	60	-0.20	0.02	0.58	3.18
		4	68	-0.03	1.18	3.60	11.71
		6	75	1.23	5.99	13.99	31.39
FI	11.7	8	60	-0.04	0.50	1.44	5.69
		4	68	0.86	4.61	11.16	27.30
		8	75	3.78	11.55	21.13	52.45

Table 2-A-2

Diurnal Emissions -- Consistent with In-Use EF Results at 9.0 RVP Standard Test

Vehicle Type	RVP (psi)	No. of Vehicles	Starting Temp(°F)	Diurnal Emissions (g/test)			
				+15°F	+20°F	+24°F	+30°F
CARB	9.0	14	60	1.94	2.12	2.32*	2.92
		5	68	2.09	2.43	2.94	4.89
		14	75	2.24	2.97	4.45	9.87
CARB	10.4	10	60	2.18	2.90	3.28	7.35
		5	68	2.46	3.43	5.45	11.76
		10	75	3.24	6.62	12.01	26.53
CARB	11.7	9	60	2.71	4.06	6.58	14.61
		5	68	3.16	6.73	12.49	25.26
		9	75	8.78	20.80	33.70	66.61
FI	9.0	10	60	1.01	1.12	1.25*	1.69
		4	68	0.95	1.20	1.83	4.63
		10	75	1.09	1.55	2.50	6.42
FI	10.4	6	60	1.05	1.27	1.83	4.43
		4	68	1.22	2.43	4.85	12.96
		6	75	2.48	7.24	15.24	32.64
FI	11.7	8	60	1.21	1.75	2.69	6.94
		4	68	2.11	5.86	12.41	28.55
		8	75	5.03	12.80	22.38	53.70

---

* From in-use EF test results.

on the whole, than the in-use vehicles tested. For instance, any obvious problems, such as the disconnected tank vent line found in one vehicle, were corrected before testing at ATL. Also, the leaking gas caps in three vehicles were replaced in order to prevent intermittent leaks from disguising actual trends in emissions versus temperature (i.e., the cap may leak during the low temperature test but not with the high temperatures, resulting in unrealistically higher emissions at low temperatures). Another reason for lower emissions is that the ATL vehicles' evaporative control systems may have been more adequately purged prior to testing, as they were driven a minimum of 45 miles to the ATL test site compared to an average of 2[illegible] miles between the homes of the in-use vehicles' owners and the EPA test site in Ann Arbor.

Because the in-use program represents a significantly larger data base (over 200 vehicles versus 24 at ATL) and because the in-use data provide the basis for emission projections made throughout this study, two more final steps were taken to make the ATL data consistent with the in-use program:

6) The normalized sets shown in Table 2-A-1 were further normalized at each RVP level (i.e., the value shown for the standard temperature conditions with 10.4 RVP was subtracted from all other values in the 10.4 data set; the same was done for the 11.7 RVP results; see Table 2-A-3);

7) Finally, the in-use EF average at each of the two RVPs (10.4 and 11.7) under standard temperatures was added to the normalized values in each of the RVP sets.

The end product of these various steps, as shown in Table 2-A-4, is a set of emission results at various temperatures that is consistent with averages from in-use EF testing at standard temperature conditions, which were developed from the much larger data base. But in addition, the impact of temperature on evaporative emission levels can now begin to be assessed. For example, a change in the diurnal temperature difference from the standard 24°F to 20°F (with a starting temperature of 60°F) can reduce fuel-injected diurnal losses by 0.13 g/test, or 10 percent, with an RVP of 9.0 psi; however, the impact at 11.7 psi is somewhat greater with a reduction of 0.94 g/test, or 15 percent. The potential impact of other changes, such as higher diurnal starting temperatures or greater diurnal temperature difference, can also be estimated from Table 2-A-4.

Again, these are only initial results based on a preliminary analysis of data from 24 vehicles. As more data become available, the analytical techniques described above will be reassessed and could be modified. In addition, the magnitude of the impact of temperature on emissions indicated

Table 2-A-3

ATL Diurnal Averages -- Normalized to All Three Standard Tests (9.0, 10.4, 11.7 RVPs)

Vehicle Type	RVP (psi)	No. of Vehicles	Starting Temp(°F)	Diurnal Emissions (g/test)			
				+15°F	+20°F	+24°F	+30°F
CARB	9.0	14	60	-0.38	-0.20	0.00	0.60
		5	68	-0.23	0.11	0.62	2.57
		14	75	-0.08	0.65	2.13	7.55
CARB	10.4	10	60	-1.10	-0.38	0.00	4.07
		5	68	-0.82	0.15	2.17	8.48
		10	75	-0.04	3.34	8.73	23.25
CARB	11.7	9	60	-3.87	-2.52	0.00	8.03
		5	68	-3.42	0.15	5.91	18.68
		9	75	2.20	14.22	27.12	60.03
FI	9.0	10	60	-0.24	-0.13	0.00	0.44
		4	68	-0.30	-0.05	0.58	3.38
		10	75	-0.16	0.30	1.25	5.17
FI	10.4	6	60	-0.78	-0.56	0.00	2.60
		4	68	-0.61	0.60	3.02	11.13
		6	75	0.65	5.41	13.41	30.81
FI	11.7	8	60	-1.48	-0.94	0.00	4.25
		4	68	-0.58	3.17	9.72	25.86
		8	75	2.34	10.11	19.69	51.01

Table 2-A-4

Diurnal Emissions -- Consistent with In-Use EF Results at All Three Standard Tests (9.0, 10.4, 11.7 RVPs)

Vehicle Type	RVP (psi)	No. of Vehicles	Starting Temp(°F)	Diurnal Emissions (g/test)			
				+15°F	+20°F	+24°F	+30°F
CARB	9.0	14	60	1.94	2.12	2.32*	2.92
		5	68	2.09	2.43	2.94	4.89
		14	75	2.24	2.97	4.45	9.87
CARB	10.4	10	60	3.82	4.54	4.92*	8.96
		5	68	4.08	5.07	7.09	13.40
		10	75	4.88	8.26	13.65	28.17
CARB	11.7	9	60	6.27	7.62	10.14*	18.17
		5	68	6.72	10.29	16.05	28.82
		9	75	12.34	24.36	37.26	70.17
FI	9.0	10	60	1.01	1.12	1.25*	1.69
		4	68	0.95	1.20	1.83	4.63
		10	75	1.09	1.55	2.50	6.42
FI	10.4	6	60	1.45	1.67	2.23*	4.83
		4	68	1.62	2.83	5.25	13.36
		6	75	2.88	7.64	15.64	33.04
FI	11.7	8	60	5.00	5.54	6.48*	10.73
		4	68	5.90	9.65	16.20	32.34
		8	75	8.82	16.59	26.17	57.49

---

* From in-use EF test results.

by the raw data could change as the vehicle sample is broadened, which could also cause these preliminary findings to change.

B. Theoretical Diurnal Emissions Index vs. Test Data

At this point, the data could simply be reduced via a multiple regression analysis. However, the amount of data available is not large and strong non-linear interrelationships between the variables are known to exist (e.g., the effect of an increase in diurnal temperature change will be much greater at high fuel RVP than low). Thus, at this point in time, it was deemed more appropriate to utilize an emission model for uncontrolled diurnal emissions to reduce the test variables to a single evaporative emission potential and then correlate actual emissions with this potential. In this way, less emphasis is placed on any individual data point and the chance of having outliers that strongly affect the results is significantly lessened.

A model of uncontrolled diurnal emissions developed by D.T. Wade in 1967 was chosen for this purpose.[41] (No hot-soak emission model was known to be readily available.) This model relies on changes in actual fuel vapor pressure, the Ideal Gas Law, and the readily predictable processes ocurring in a vehicle's fuel tank to predict uncontrolled diurnal losses from a fuel tank as a function of fuel characteristics (including RVP) and temperature conditions. The concepts involved in the modeling of diurnal losses are fairly straightforward; however, minor errors can exist. For instance, the assumption that the vapor pressure at the midway point between the starting and ending diurnal temperatures is the same as the average of the initial and final vapor pressures may involve a small amount of error. Wade compared his predicted uncontrolled levels to fuel tank running losses measured during road and dynomometer tests.[41] Although running losses differ from diurnal emissions as we have referred to them here, the same basic principles apply because both types of losses occur in response to an increase in fuel tank temperature. Wade found that his model was better at predicting losses measured during the road tests than with the dynomometer tests, most likely because equilibrium between the liquid and vapor phases within the fuel tank was better maintained during the road tests. Correlation between the predicted values and the dynomometer measurements was rather poor, especially as the losses increased.[41] However, as actual in-use conditions would most closely parallel the road tests, the model should be suitable when used to predict the relative impacts of various field conditions.

Wade's model can be used to predict absolute uncontrolled diurnal losses (i.e., grams of HC emitted from the fuel tank) for any given set of conditions; however, its use here was to predict relative losses and not absolute values. More specifically, Wade's model was used here to calculate a relative index of theoretical uncontrolled diurnal emissions which could be related to measurements of controlled diurnal emissions under various conditions to produce a diurnal emissions model. An index of 1.00 was assigned to the standard diurnal test (i.e., 60-84°F, 9.0 RVP Indolene).

Wade's equation for uncontrolled diurnal losses is as follows:

$$G = 454\ W \left(\frac{520}{690 - 4M}\right) \left(\frac{\bar{p}}{P_t - \bar{p}}\right) \left[\left(\frac{(P_t - p_1)\ V_1}{T_1}\right) - \left(\frac{(P_t - p_2)\ V_2}{T_2}\right) \right]$$

where:

G = Weight hydrocarbon lost, g
W = Fuel density, lb/gal
M = Molecular weight of hydrocarbon vapor, lb/lb mole at average liquid temperature
p = Vapor pressure of gasoline, psia, at liquid tempertemperature corresponding to T
P = Total pressure, psia

$$\bar{p} = \frac{p_1 + p_2}{2} \text{ psia}$$

V = Volume of vapor space, cu ft
T = Temperature, R

Subscripts:

t = Tank
1 = Initial state
2 = Final state

The relative emissions index mentioned earlier was calculated as the ratio of G_{test} (using various test temperatures and RVPs) to G_{std} (based on the 60-84°F diurnal test with 9.0 RVP Indolene). Assumptions made with respect to the volume of the vapor space were that $V_1 = V_2$ and $V_{test} = V_{std}$, so the term V essentially drops out of the equation. The tank was assumed to be at atmospheric pressure, so the term $P_t = 14.7$ psia. Actual HC vapor pressures were read from an API nomograph as a function of temperature and RVP.* Values substituted for W (fuel density) and M (molecular weight) are listed below as a function of fuel RVP:

RVP	W(lbs/gal)	M(lb/lb mole)
9.0	6.22	64.0
10.4	6.19	62.6
11.7	6.17	61.3

An emissions index was calculated for each of the diurnal temperature conditions at each of the three fuel RVPs listed in the test matrix in Part A. Because the model is applicable only to diurnal emissions, no indexes were calculated for the hot-soak conditions, and hot-soak losses are not considered in this Appendix. Table 2-A-5 lists the indexes calculated for each test condition. As shown, the standard certification evaporative test (60-84°F) on 9.0 RVP Indolene is assigned an index of 1.00, by definition. Those conditions with an index of less than 1.00 would theoretically be expected to produce lower diurnal losses than the certification test, and vice versa.

The indexes for each test condition were then plotted versus the diurnal emissions levels developed in Part A. Separate graphs were prepared for carbureted and fuel-injected vehicles, shown respectively in Figures 2-A-1 and 2-A-2. Two curves are shown on each figure. Curve #1 represents the ATL emissions data normalized only to the 9.0 RVP standard test; this approach was discussed previously in Steps 1-5 and the resulting emission levels were shown in Table 2-A-2. Curve #2 shows the ATL data as it was further normalized at all three RVPs (described earlier in Steps 6 and 7, and shown in Table 2-A-4). Both curves are included due to uncertainty as to the most appropriate analytical approach to be taken. In fact, future analysis may lead to an entirely different approach, but these two are offered here.

---

* The nomograph is Figure 5B1.1, "True Vapor Pressure of Gasolines and Finished Petroleum Products," from API's Technical Data Book, September 1977.

Table 2-A-5

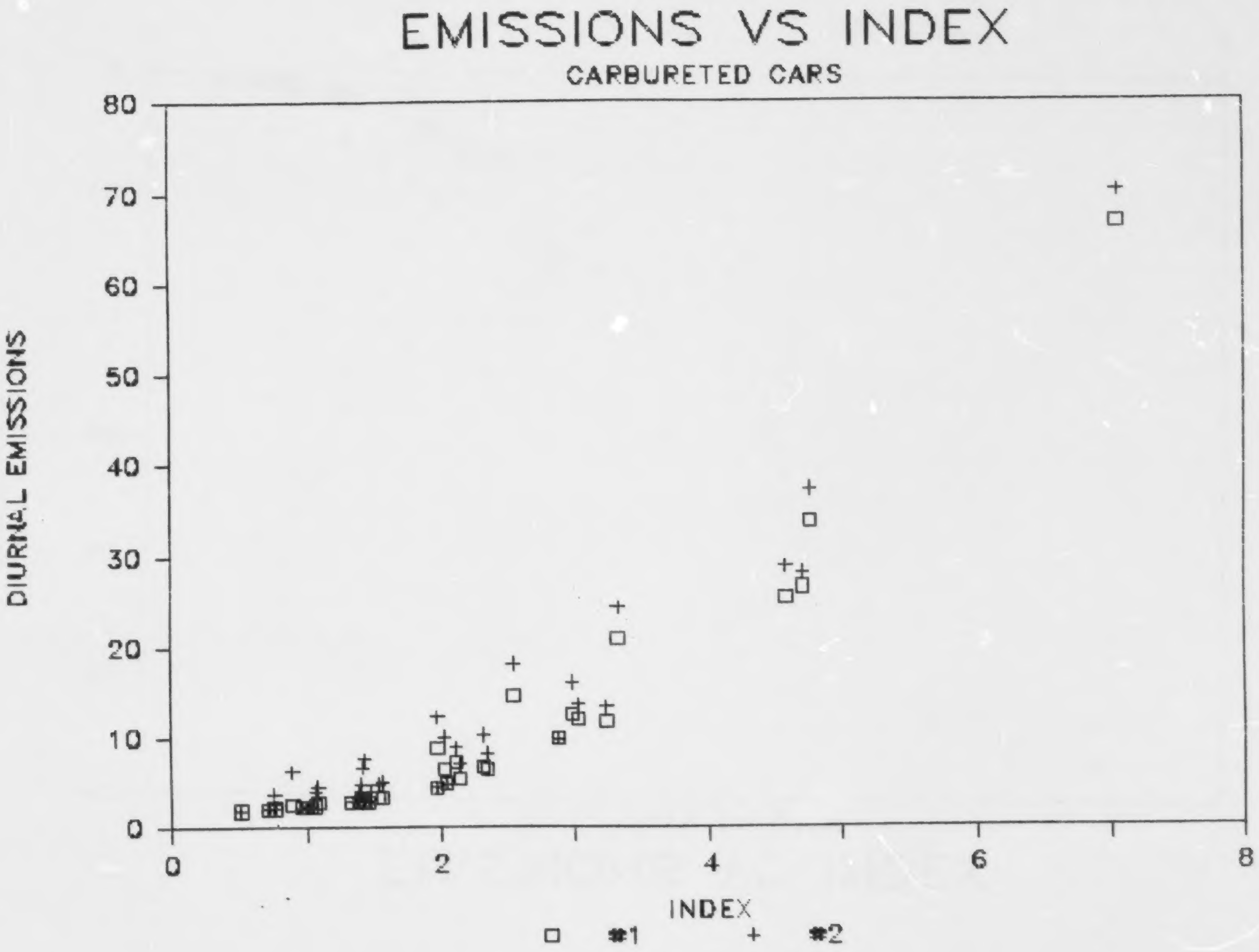
Calculated Emission Indexes for Each ATL Diurnal Test Condition

Test No.	RVP (psi)	Starting Temp (°F)	Diurnal Charge (°F)	Emissions Index
1	9.0	60	+15	0.51
2			+20	0.77
3			+24	1.00*
4			+30	1.45
5		68	+15	0.71
6			+20	1.03
7			+24	1.33
8			+30	2.04
9		75	+15	0.96
10			+20	1.42
11			+24	1.96
12			+30	2.88
13	10.4	60	+15	0.76
14			+20	1.08
15			+24	1.52
16			+30	2.11
17		68	+15	1.06
18			+20	1.56
19			+24	2.14
20			+30	3.24
21		75	+15	1.40
22			+20	2.34
23			+24	3.03
24			+30	4.71
25	11.7	60	+15	0.89
26			+20	1.42
27			+24	2.02
28			+30	2.54
29		68	+15	1.41
30			+20	2.31
31			+24	2.98
32			+30	4.58
33		75	+15	1.97
34			+20	3.33
35			+24	4.76
36			+30	7.05

---

* Current EPA certification test conditions.

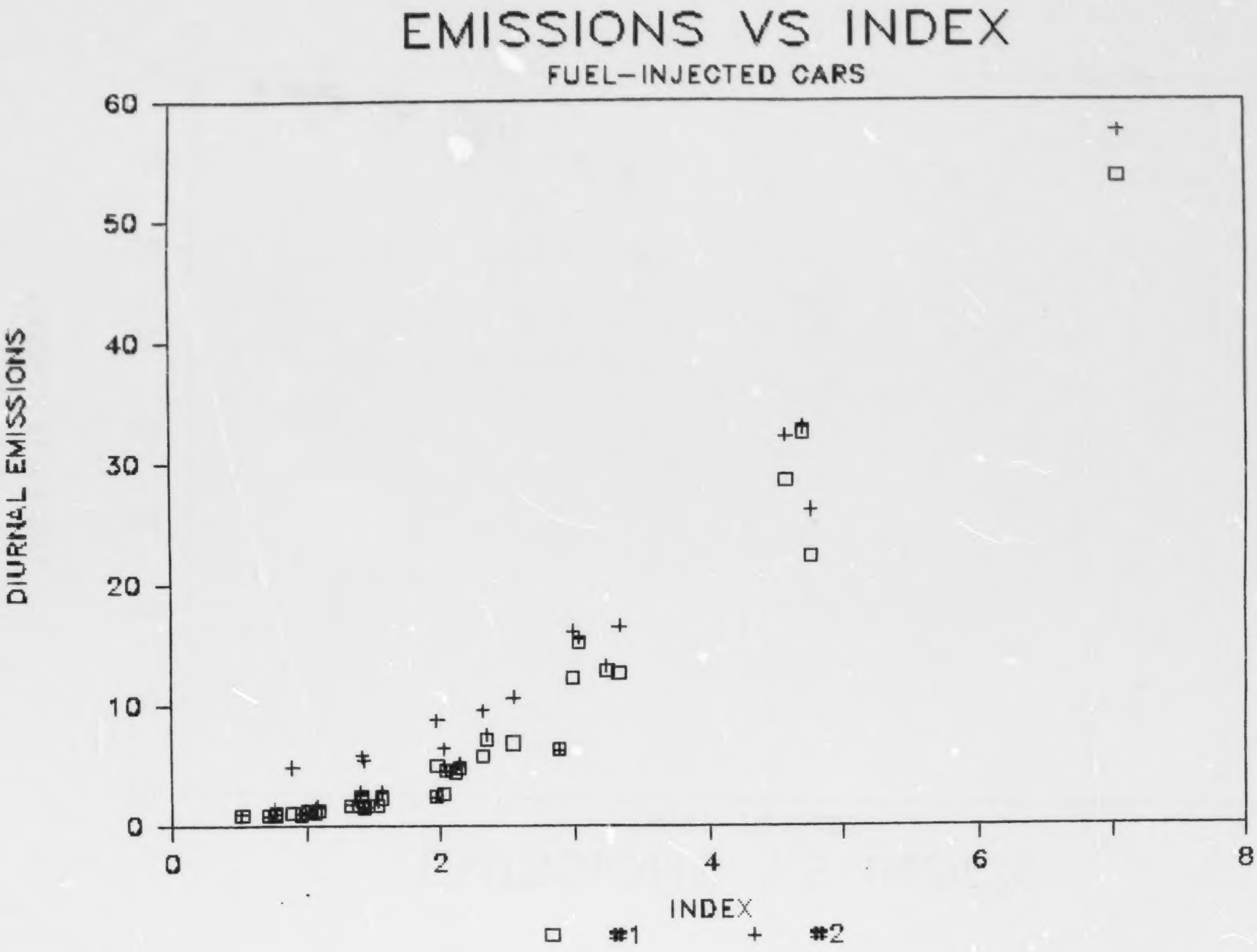
Figure 2-A-1



EMISSIONS VS INDEX

CARBURETED CARS

Figure 2-A-2


EMISSIONS VS INDEX
FUEL-INJECTED CARS
DIURNAL EMISSIONS
60
50
40
30
20
10
0
0
2
4
6
8
INDEX
□ #1
+ #2

C. City Temperature Conditions vs. EPA Test Conditions

This final portion of this Appendix makes a preliminary attempt to evaluate how representative EPA's current and proposed certification test procedures are of conditions in various ozone non-attainment areas. The comparisons will make use of Wade's diurnal emissions model once again, and therefore hot-soak losses will not be discussed. No attempt will be made here to predict absolute emissions in any of the urban areas examined, but rather relative city temperature and RVP differences will be assessed with respect to EPA's test conditions. As mentioned earlier, after careful analysis of all data, efforts may be made in the future to make MOBILE3 city-specific in its modelling of evaporative HC emissions. It is important to note, however, that any methodologies or techniques used in this Appendix do not necessarily represent the approach that will be taken in any modification of the MOBILE program.

For this analysis, two basic comparisons were made. The first evaluates current city-specific conditions, including actual summertime RVPs from MVMA's 1984 Summer Gasoline Survey [14], against EPA's current certification test for diurnal losses -- a 60-84°F temperature excursion with 9.0 RVP Indolene test fuel. The second comparison is more representative of future conditions, assuming ASTM's volatility limits will be reached in each of the urban areas and comparing these city-specific conditions to a proposed certification test -- using an RVP of 11.5 psi with the same diurnal temperature excursion of 60-84°F. Both comparisons make use of the same temperature data for each of the cities -- 30-year average minimum and maximum July temperatures.* In future work, one possible refinement would be the use of temperatures from days on which ozone violations have actually occurred within each area. However, for this analysis, typical July temperatures were chosen because July is one of the two months shown to be most prone to ozone episodes (the other is August, as indicated earlier in this chapter in Table 2-4).

From the list of 47 non-attainment areas shown earlier in Table 2-1, 17 were included in MVMA's 1984 Summer Gasoline Survey.[14] Because current city-specific RVPs were needed for the first comparison, only these 17 areas were included in this analysis.

---

* Temperatures were taken from the Climatography of the United States, U.S. National Oceanic and Atmospheric Administration, and The Weather Almanac, Gale Research Company.

City-specific inputs for the first comparison are shown in Table 2-A-6. Temperatures are shown in Fahrenheit degrees, but were converted to Rankin for use in Wade's equation. City RVPs shown are from the MVMA survey. All other variables (i.e., W, M, p_2 and p_1) are a function of RVP and temperature. Using these inputs, a relative diurnal index was calculated for each of the cities using Wade's equation; again, the standard EPA test with 9.0 RVP Indolene is given an index of 1.00. Final indexes for each city are shown in Table 2-A-7.

For these city-specific index calculations, the effect of fuel "weathering" on volatility and, thus, evaporative emissions was also accounted for. As discussed earlier in Section IV.B. of Chapter 2, General Motors estimated that diurnal emissions were roughly 15 percent lower with weathered fuel than with non-weathered Indolene at the 40-percent full tank level specified in EPA's test procedure.[16] For purposes of this analysis, a constant factor of 0.85 was applied to the city-specific portion of the diurnal index (i.e., the numerator) to account for this 15-percent decrease in emissions due to fuel weathering in the field. Because EPA's test fuel is not weathered, the 0.85 factor is not applied in determining G_{std} (the denominator of the index). (This weathering effect has already been incorporated into the indexes shown in Table 2-A-7.)

As indicated in Table 2-A-7, the current certification test on Indolene appears to significantly underestimate diurnal emissions in the majority of the ozone non-attainment cities examined. In only two of the 17 cities (Boston and Atlanta) do diurnal losses appear to be slightly overestimated by the certification test -- indicated by an index of less than one. These results are not surprising as current RVPs in most of the cities examined are much greater than 9.0 psi.

The second question to be answered concerns the future: "If RVPs in all areas reach the ASTM summer (July) limits, will the certification diurnal test be representative of these areas if test fuel RVP is raised to 11.5 psi (instead of the current 9.0 psi)?" In order to address this question, city-specific indexes were recalculated using the inputs shown in Table 2-A-8. Temperatures are the same as before (i.e., 30-year average July minimums and maximums), but here the RVPs shown are the current ASTM July limits for each of the cities.* Of course, the remaining variables also change because of their dependence on RVP. Weathering was again included in the city-specific calculations.

---

* This is true except for three cities--Chicago, Cleveland, and St. Louis--where current RVPs are already above their respective ASTM limits. In these cases, the MVMA survey RVPs were used (i.e., same as in Table 2-A-6).

Table 2-A-6
City-Specific Inputs for First Index Calculation (Using Survey RVPs)

City	T_2 (°F)*	T_1 (°F)*	MVMA Survey RVP (psi)**	W (lb/gal)	M (lb/lb mole)	P_2 (psi)	P_1 (psi)
Chicago	83.1	60.7	11.8	6.17	61.2	9.4	6.4
Cleveland	81.6	61.2	11.7	6.17	61.3	9.1	6.3
Detroit	83.1	63.4	11.4	6.17	61.6	8.9	6.3
Boston	81.4	65.1	11.0	6.18	62.0	8.4	6.3
NYC	85.2	68.0	11.3	6.18	61.7	9.2	6.8
Wash., DC	88.2	69.1	10.6	6.19	62.4	9.2	6.5
Phila.	86.8	66.7	11.0	6.18	62.0	9.3	6.5
Miami	89.1	75.5	10.5	6.19	62.5	9.2	7.3
Kansas City	88.0	66.9	10.0	6.20	63.0	8.6	5.9
St. Louis	88.4	68.8	10.5	6.19	62.5	9.1	6.4
Dallas	95.5	74.0	10.0	6.20	63.0	9.7	6.7
San Antonio	94.0	74.0	10.0	6.20	63.0	9.4	6.7
Atlanta	86.5	69.4	9.7	6.21	63.3	8.0	5.9
New Orleans	90.4	73.3	10.5	6.19	62.5	9.5	6.9
Phoenix	104.8	77.5	8.4	6.23	65.2	9.5	6.0
Las Vegas	103.9	75.3	8.3	6.24	65.4	9.3	5.6
Denver	87.4	58.6	9.2	6.22	63.8	7.8	4.6
EPA Test (Current)	84.0	60.0	9.0	6.22	64.0	7.2	4.6

---

* Temperatures are 30-year average normal daily maximums (T_2) and minimums (T_1) for the month of July. (Sources: Climatography of the United States, U.S. National Oceanic and Atmospheric Administration, and The Weather Almanac, Gale Research Company)

** Average city RVPs from the MVMA National Gasoline Survey -- Summer Season 1984.

Table 2-A-7

Current EPA Test vs. Calculated City-Specific Diurnal Indexes (Using Survey RVPs)

City	"Current" Diurnal Index
Chicago	1.56
Cleveland	1.38
Detroit	1.25
Boston	0.96
NYC	1.27
Wash., DC	1.38
Philadelphia	1.45
Miami	1.07
Kansas City, MO	1.20
St. Louis	1.35
Dallas	1.67
San Antonio	1.45
Atlanta	0.87
New Orleans	1.44
Phoenix	1.77
Las Vegas	1.74
Denver	1.12
EPA Indolene Test (Current)	1.00

Table 2-A-8

City-Specific Inputs for Second Index Calculation (Using ASTM's July RVP Limits)

City	T_2 (°F)*	T_1 (°F)*	ASTM RVP Limit (psi)**	W (lb/gal)	M (lb/lb mole)	P_2 (psi)	P_1 (psi)
Chicago	83.1	60.7	11.8	6.17	61.2	9.4	6.4
Cleveland	81.6	61.2	11.7	6.17	61.3	9.1	6.3
Detroit	83.1	63.4	11.5	6.17	61.5	9.0	6.3
Boston	81.4	65.1	11.5	6.17	61.5	8.7	6.5
NYC	85.2	68.0	11.5	6.17	61.5	9.4	7.0
Wash., DC	88.2	69.1	11.5	6.17	61.5	9.9	7.1
Phila.	86.8	66.7	11.5	6.17	61.5	9.7	6.8
Miami	89.1	75.5	11.5	6.17	61.5	10.0	7.9
Kansas City	88.0	66.9	10.0	6.20	63.0	8.6	5.9
St. Louis	88.4	68.8	10.5	6.19	62.5	9.1	6.4
Dallas	95.5	74.0	10.0	6.20	63.0	9.7	6.7
San Antonio	94.0	74.0	10.0	6.20	63.0	9.4	6.7
Atlanta	86.5	69.4	11.5	6.17	61.5	9.7	7.1
New Orleans	90.4	73.3	11.5	6.17	61.5	10.3	7.7
Phoenix	104.8	77.5	9.0	6.22	64.0	10.4	6.5
Las Vegas	103.9	75.3	9.0	6.22	64.0	10.3	6.1
Denver	87.4	58.6	10.0	6.20	63.0	8.6	5.0
EPA Test (Future)***	84.0	60.0	11.5	6.17	61.3	9.3	6.0

---

* Temperatures are 30-year average normal daily maximums (T_2) and minimums (T_1) for the month of July. (Sources: Climatography of the United States, U.S. National Oceanic and Atmospheric Administration, and The Weather Almanac, Gale Research Company)

** ASTM's maximum RVP specification for the month of July for each area, except where current levels already exceed ASTM limits.

*** As assumed in this analysis.

Indexes for this second comparison were calculated as before (i.e., the denominator based on standard Indolene test conditions) and are shown in Table 2-A-9. As indicated there, most of the indexes have increased in comparison to those in Table 2-A-7. This is entirely due to the assumed increase in RVP as ASTM limits are reached. The exceptions occur in six cities where the indexes do not change because their current RVPs are either just at or above the ASTM limits (i.e., inputs are the same for these particular cities in both Tables 2-A-6 and 2-A-8).

In this part of the analysis, the city-specific indexes are most appropriately compared to the index calculated for the future test conditions implicit in this study -- a 60-84°F diurnal temperature excursion with an RVP of 11.5 psi. This index, also shown in Table 2-A-9, is 1.89; because this involves a test fuel, no weathering effect was accounted for here. As shown, if certification RVP were revised to 11.5 psi with no change in the current test temperatures, the test would then ensure that vehicles' evaporative control systems were designed to operate properly in the majority of U.S. cities. As shown in Table 2-A-9, only two of the 17 cities (Phoenix and Las Vegas) have indexes greater than 1.89 (that of the future test procedure), indicating theoretically higher diurnal losses.

D. Summary

A few basic conclusions can be made from the analyses presented in this Appendix. First, diurnal and hot-soak losses can increase dramatically with higher temperatures as well as with higher RVPs. The effect of higher RVPs had already been fairly well-defined via EPA's in-use EF testing (as described in detail earlier in Chapter 2). However, the effect of temperature on evaporative emissions has not been examined to nearly such a great extent, as the ATL testing represents EPA's first significant work in this area. As shown in Part A of this Appendix, initial ATL test data show emissions to be somewhat less sensitive to RVP than do the in-use EF test results, which could imply that perhaps the ATL results are also underestimating the effect of temperature. However, as more vehicles are added to the ATL sample, trends in the results could change and become more consistent with the in-use EF data.

Some preliminary conclusions regarding the representativeness of EPA's current certification procedure can be made based on the analysis in Part C of this Appendix. Using the diurnal emissions index based on Wade's equation, it was shown that the variety of summer temperature and RVP conditions typical of several of the ozone non-attainment areas could theoretically result in a rather wide range of diurnal

Table 2-A-9

Future* EPA Test vs. Calculated City-Specific Diurnal Indexes (Using ASTM's July RVP Limits)

City	"Future" Diurnal Index
Chicago	1.56
Cleveland	1.38
Detroit	1.31
Boston	1.06
NYC	1.34
Wash., DC	1.67
Philadelphia	1.63
Miami	1.40
Kansas City, MO	1.20
St. Louis	1.35
Dallas	1.67
San Antonio	1.45
Atlanta	1.51
New Orleans	1.76
Phoenix	2.32
Las Vegas	2.34
Denver	1.44
EPA 11.5-RVP Test (Future)*	1.89

---

* As assumed in this analysis.

losses. However, the majority of these predicted relative levels are greater than that predicted for the current standard diurnal test conditions (i.e., 60-84°F, 9.0 psi RVP). Therefore, the premise made in Chapter 2 that EPA's current certification test is underestimating summertime diurnal losses in the majority of the urban areas appears to be confirmed. Results of this initial analysis support the position that the current test conditions need to be modified -- either in terms of RVP or temperatures, or both -- in order to be more representative of conditions in the field. The change examined here -- raising certification fuel RVP to 11.5 psi without any other modifications -- would appear to result in vehicles being properly designed for typical summer days in most of the cities examined. However, an examination of days on which actual ozone violations have occurred may show more severe temperature conditions than the 30-year July averages, and could result in higher city-specific indexes.

As alluded to earlier, one of EPA's future goals is to incorporate city-specific information on diurnal and hot-soak temperatures, RVP, and perhaps weathering into the modelling of evaporative HC emissions. Additional information is needed before this task can be accomplished with confidence. Following completion of the ATL testing, the objective is to develop two models -- one for diurnal and one for hot-soak losses -- that can be used to predict emissions from controlled vehicles (i.e., equipped with a canister) as a function of both RVP and temperature conditions. Then, as city-specific conditions are defined, the appropriate diurnal and hot-soak losses could be determined and input into MOBILE3. In addition, more information on the effect of fuel weathering in the field is needed before it can be incorporated into the emissions modelling. The effect of weathering on fuel volatility -- as opposed to the effect on emissions -- will most likely be the focus here. The weathering effect could then enter into the analysis as a direct adjustment of each city-specific RVP before it is read into the diurnal and hot-soak models.

Appendix 2-B

Breakdown of Motor Vehicle Evaporative Emission Factors into Their Components

I. Introduction

The evaporative emission factors used in this analysis were derived from the results of EPA's in-use emission factor (EF) test program. From July 1984 until April 1985, 164 vehicles were tested under this program. These vehicles were tested on 1) commercial fuel with a nominal RVP of 11.7 psi, 2) a blended fuel with an RVP of 10.4 psi, and 3) Indolene fuel, with an RVP of roughly 9.0 psi, in that order. The complete test procedure has been summarized in Table 2-11 under the heading of Post-July 1984.

The vehicles in the EF testing program have been separated by the condition of the vehicle, and by type of fuel metering system. Those vehicles having evaporative emission control malfunctions considered to be tampering were placed in the category of "tampered" vehicles. The remaining vehicles were categorized as "non-tampered" vehicles. As a subset of this group, those vehicles which exhibited no evaporative control system malfunctions were categorized as "problem-free" vehicles. Table 2-14 listed the potential malfunctions in the evaporative control systems, and noted those that were considered tampering. Within each of the above categories, the vehicles have also been separated into carbureted and fuel-injected vehicles.

Through consideration of the different evaporative emission rates for each of these categories, the individual components of the final evaporative emission factors were determined. These components are: 1) the standard level, 2) the insufficient design effect, 3) the malmaintenance and defect effect, 4) the excess RVP effect, and 5) the tampering effect. The magnitude of the first four of these components were determined directly from the EF data. The in-use EF sample is not thought to have a representative number of tampered vehicles, however, so the magnitude of the tampering effect has not been developed from this testing, and will therefore be discussed separately. These components are later used to determine the evaporative emission factors for the various control scenarios in Chapter V.

II. Non-Tampered Vehicle Evaporative Emission Rates

The average measured emission rates for non-tampered vehicles for each of the three fuels tested is shown in the top portion of Table 2-B-1. However, this analysis requires that the emission rates be known for in-use RVPs other than just these three levels. Therefore, curves were fit through the data for both diurnal and hot-soak emissions for each type of fuel metering system. The emission rates from these curves are summarized in the bottom part of Table 2-B-1. Note that the rates from the curves at 9.0, 10.4, and 11.7 psi differ slightly from the actual test data.

These emission rates have been separated into the four non-tampered components listed previously. The remainder of this section will describe the process by which the magnitude of each component was determined, and how they were extrapolated from light-duty vehicles to light-duty trucks and heavy-duty vehicles.

A. Standard Levels

The standard levels represent the emission rates that would be seen if the vehicles emitted just at the current 2-gram/test LDV standard on 9.0 RVP fuel. As it is necessary to break this level down into diurnal and hot-soak losses (which vary from vehicle to vehicle), it is assumed that the ratio of hot-soak to diurnal emissions from problem-free vehicles is the same that would be seen if the standard level were met. Therefore, all that needs to be done to determine the standard levels is to normalize the hot-soak and diurnal emissions on 9.0 RVP fuel from the problem-free sample such that their sum equals 2 grams/test. The emission rates observed from the problem-free vehicles and the calculated standard levels are presented in the first parts of Table 2-B-2.

B. Insufficient Purge Design Effect

The differences between the standard levels and the problem-free emission rates on 9.0 RVP fuel represent the effect of insufficient purge system design. This is based upon the assumption that an operating evaporative control system with no malfunctions should meet the 2-gram/test standard. This effect is determined by simply subtracting the calculated standard levels from the emission rates for problem-free vehicles on 9-psi RVP fuel, as shown at the bottom of Table 2-B-2. Note that for fuel-injected vehicles this effect is non-existent, as their problem-free average emissions on 9-psi RVP fuel are under 2 grams/test.

Table 2-B-1

Non-Tampered 81+ LDV and LDT Evaporative Emission Rates (g/test)

EF Test Data

Fuel Metering System	RVP(psi)	Hot-Soak	Diurnal
CARB	9.0	2.33	2.36
	10.4	2.93	4.92
	11.7	4.05	10.14
FI	9.0	0.93	1.21
	10.4	1.38	2.23
	11.7	1.92	6.48

Fitted Curves

Fuel Metering System	RVP(psi)	Hot-Soak	Diurnal
CARB	9.0	2.32	2.32
	9.5	2.46	3.04
	10.0	2.68	4.06
	10.5	2.98	5.40
	11.0	3.37	7.05
	11.5	3.84	9.01
FI	9.0	0.90	1.25
	9.5	1.08	1.59
	10.0	1.27	1.93
	10.5	1.46	2.34
	11.0	1.65	3.68
	11.5	1.83	5.51

Table 2-B-2

Estimation of Standard Level and Insufficient Purge Effect for 81+ LDVs and LDTs (g/test)

Problem-Free Vehicle Average with 9.0 RVP	Hot Soak	Diurnal
CARB	1.50	1.25
FI	0.64	0.87
Standard Level*		
CARB	1.09	0.91
FI	0.85	1.15
Insufficient Design/Capacity Purge Effect**		
CARB-Straight	0.41	0.34
-Adjusted	0.30	0.30
FI	0.00	0.00

---

* Problem-free average normalized to 2-gram standard.

** Problem-free average minus standard level; if negative, as for FI vehicles, considered zero.

These insufficient design effect values for carbureted vehicles require an additional, very slight adjustment due to the fact that the curve fits described in the previous section do not exactly match the EF data. These adjusted values are also shown in Table 2-B-2. The differences between the straight and adjusted values are equivalent to the differences at 9.0 RVP between the EF data for non-tampered vehicles and those given by the fitted curves. Without this adjustment, the component values would not sum to the average emission level for non-tampered vehicles in the EF sample.

C. Malmaintenance and Defect Effect

Non-tampered vehicles, on the whole, show significantly higher average evaporative emission rates than do problem-free vehicles (a subset of non-tampered vehicles). This effect is assumed to be due to improper maintenance and equipment defects in the evaporative emission control system, but not to deliberate tampering. (The distinction between malmaintenance/defects and tampering was made earlier in Table 2-14 of Chapter 2.)

The magnitude of the effect of malmaintenance and defects upon evaporative emission rates was found to increase with fuel RVP. The determination of this relationship for diurnal emissions from carbureted vehicles is shown graphically in Figure 2-B-1. The top line shows the average emission rates at the 3 fuel RVPs for all non-tampered vehicles; the middle line shows these rates for only problem-free vehicles; and the bottom line shows the difference between the top two lines. A simple linear regression passing through the value at 9.0 RVP has been fitted to the values at 10.4 and 11.7 RVP to arrive at this "difference" curve. This same method was used to develop the relationships for carbureted hot-soak, fuel-injected diurnal, and fuel-injected hot-soak emissions.* The resulting malmaintenance and defect effects are summarized in Table 2-B-3.

---

* Two carbureted 1983 Nissan Stanzas in the problem-free sample had unexplainably high (>23 grams/test) hot-soak emissions that skewed the results such that the malmaintenance and defect effect decreased with increasing RVP. The removal of the hot-soak results for these two vehicles from the problem-free sample corrected this problem. Therefore, this approach was taken for this portion of the analysis.

FIGURE 2-B-1

CARBURETED DIURNAL EMISSIONS

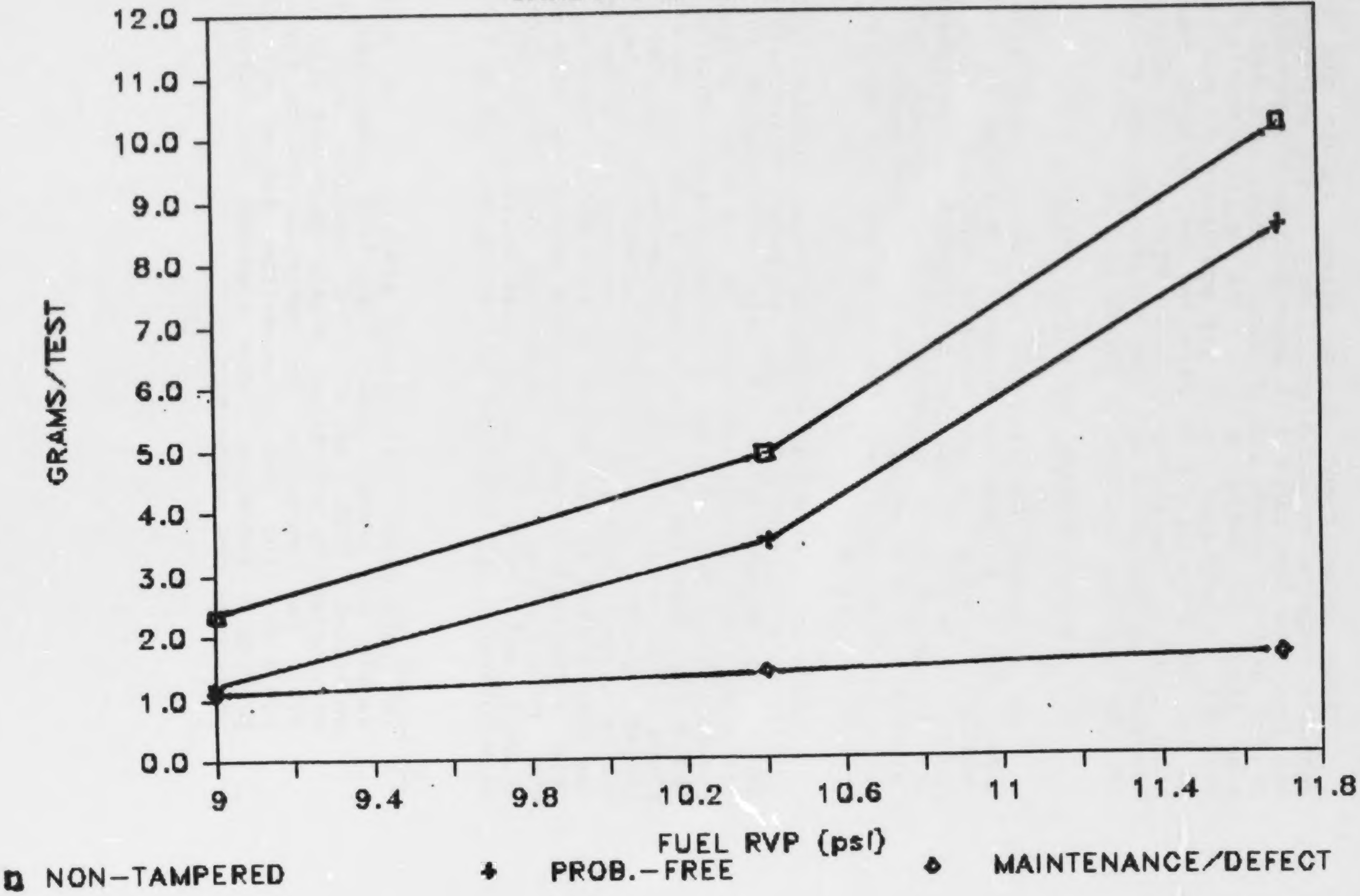


Table 2-B-3

Malmaintenance and Defect Effect for 81+ LDVs and LDTS (grams/test)

Fuel Metering System	RVP (psi)	Hot Soak	Diurnal
CARB	9.0	0.83	1.11
	9.5	0.91	1.21
	10.0	0.99	1.31
	10.5	1.07	1.41
	11.0	1.15	1.51
	11.5	1.24	1.61
FI	9.0	0.29	0.34
	9.5	0.42	0.44
	10.0	0.55	0.54
	10.5	0.67	0.64
	11.0	0.81	0.74
	11.5	0.93	0.84

D. Excess RVP Effect

The RVP effect represents the excess evaporative emissions that arise from operating vehicles on a fuel of a higher volatility that for which they were designed. Current evaporative control systems are designed to meet the 2-gram/test standard when operated on Indolene, with an average RVP of 9.0 psi. Current in-use gasolines in many areas of the country, however, have average volatilities well above 9.0 psi.

The magnitude of the RVP effect will of course depend upon the actual volatility of the in-use fuel. Herein, this magnitude is generally defined as the difference between non-tampered evaporative emissions on commercial fuel and Indolene, adjusted to reflect the effect that fuel volatility has upon the malmaintenance and defect effect. Without this latter correction a situation of double counting would arise. As an example, calculation of the excess RVP effect on diurnal emissions from carbureted vehicles operating on 11.5-psi fuel is reviewed below.

Using the fitted curve values listed in Table 2-B-1, the total difference between the carbureted diurnal losses at 11.5 RVP (9.01 g/test) and 9.0 RVP (2.32 g/test) is calculated as 6.69 g/test. However, part of this total difference in non-tampered emissions has already been accounted for in the RVP-dependent malmaintenance/defect effect. As Table 2-B-3 shows, the difference between the 11.5 RVP and 9.0 RVP diurnal effects for carbureted vehicles is 0.50 g/test (i.e., 1.61 minus 1.11). Therefore, the net effect to be attributed to excess RVP is simply the difference between 6.69 and 0.50, or 6.19 g/test. This value, along with the estimated excess RVP effect for each of the other cases, is shown in Table 2-B-4.

E. Extrapolation of LDV Data to LDTs and HDGVs

The extrapolation of the light-duty vehicle evaporative emission rates to light-duty trucks and heavy-duty vehicles is done here exactly as it was done for MOBILE3.* Basically, since little or no in-use test data exist for these vehicles, the emission rates are extrapolated based upon their relative standard levels. For LDTs, this means that evaporative emission rates will be exactly the same as for LDTs, as both of these vehicle classes must meet the same 2.0-gram/test standard under identical test procedures.

Beginning with the 1985 model year, HDGVs must meet either a 3.0-gram/test or 4.0-gram/test standard, depending upon their gross vehicle weight. Therefore, the evaporative emission rates for HDGVs under the 3.0- and 4.0-gram standards are those

---

* See Reference 50 of Chapter 2.

Table 2-B-4

Excess RVP Effect for 81+ LDVs and LDTs (g/test)

Fuel Metering System	RVP (psi)	Hot-Soak	Diurnal
CARB	9.0	0.00	0.00
	9.5	0.06	0.62
	10.0	0.20	1.54
	10.5	0.42	2.78
	11.0	0.73	4.33
	11.5	1.11	6.19
FI	9.0	0.00	0.00
	9.5	0.05	0.24
	10.0	0.11	0.48
	10.5	0.18	0.79
	11.0	0.24	2.03
	11.5	0.29	3.76

for light-duty vehicles multiplied by 1.5 and 2.0, respectively, weighted by their respective sales fractions projected for 1987 -- 81.5 percent for 3-gram and 18.5 percent for 4-gram vehicles. This yields an overall heavy-duty/light-duty multiplicative factor of 1.5925. Heavy-duty vehicles are assumed to be completely carbureted, so the evaporative emission factors from only the carbureted vehicles are used. The resulting evaporative emission factors and the magnitude of each of the various components are shown in Table 2-B-5.

III. Tampering Effect

The emission rates for tampered vehicles have been derived from SHED testing on light-duty vehicles with removed canisters and/or fuel caps. The results of this SHED testing, which was performed using 9.0 and 11.5 RVP fuels, are shown in the top portion of Table 2-B-6. The values for fuels of other RVPs were determined through linear interpolation. Certain assumptions were made as part of this testing. First, uncontrolled diurnal emissions were assumed to be the same regardless of either the type of disablement or the vehicle's fuel metering system. Secondly, for fuel-injected vehicles, uncontrolled hot-soak emissions are assumed to be the same for either canister or fuel cap removal. Finally, for carbureted vehicles, fuel cap removal is assumed not to lead to any increases in hot-soak emissions (i.e., the uncontrolled values are the same as the non-tampered hot-soak averages shown in Table 2-B-1).

The differences between these uncontrolled emissions and those of non-tampered vehicles are defined as the "tampering offsets" to be used in the MOBILE3 program, along with tampering frequency estimates. These offsets are given in the bottom half of Table 2-B-6.

Again, LDV data on uncontrolled evaporative emissions were used to develop the LDT and HDGV estimates, due to lack of evaporative testing on these classes. As before, the tampering offsets for LDTs were assumed to be equal to those developed from the LDV data, as indicated in Table 2-B-6. The methodology used to develop uncontrolled estimates for HDGVs is similar to that mentioned previously with respect to the non-tampered averages (i.e., as outlined in Reference 50 of Chapter 2). Variations from the basic MOBILE3 method of extrapolating LDV evaporative data to HDGVs will be detailed in an upcoming EPA technical report, entitled "The Effect of Fuel Volatility on Controlled and Uncontrolled Evaporative Emissions," which is expected to be released by the end of the year. Uncontrolled estimates and tampering offsets (calculated as before -- i.e., uncontrolled minus non-tampered averages) for HDGVs are presented in Table 2-B-7.

Table 2-B-5

Evaporative Emission Rates for Non-Tampered 85+ HDGVs(g/test)

Component	RVP (psi)	Hot-Soak	Diurnal
Standard Level	-	1.73	1.44
Insufficient Design Capacity/Purge	-	0.64	0.48
Malmaintenance/Defect	9.0	1.32	1.77
	9.5	1.45	1.93
	10.0	1.58	2.09
	10.5	1.71	2.25
	11.0	1.84	2.41
	11.5	1.97	2.57
Excess RVP	9.0	0.00	0.00
	9.5	0.09	0.98
	10.0	0.31	2.46
	10.5	0.67	4.43
	11.0	1.15	6.90
	11.5	1.77	9.85
Total Non-Tampered Average	9.0	3.69	3.69
	9.5	3.91	4.83
	10.0	4.26	6.47
	10.5	4.75	8.60
	11.0	5.36	11.23
	11.5	6.11	14.34

Table 2-B-6

81+ LDV and LDT Tampering*

Uncontrolled Emission Rates (g/test)

Fuel Metering System	RVP (psi)	Canister Removal		Gas Cap Removal	
		Hot-Soak	Diurnal	Hot-Soak	Diurnal
CARB	9.0	10.36	14.95	2.32	14.95
	9.5	11.79	17.10	2.46	17.10
	10.0	13.21	19.25	2.68	19.25
	10.5	14.63	21.41	2.98	21.41
	11.0	16.05	23.56	3.37	23.56
	11.5	17.47	25.71	3.84	25.71
FI	9.0	4.93	14.95	4.93	14.95
	9.5	6.26	17.10	6.26	17.10
	10.0	7.59	19.25	7.59	19.25
	10.5	8.93	21.41	8.93	21.41
	11.0	10.26	23.56	10.26	23.56
	11.5	11.59	25.71	11.59	25.71

Tampering Offsets (g/test)

Fuel Metering System	RVP (psi)	Canister Removal		Gas Cap Removal	
		Hot-Soak	Diurnal	Hot-Soak	Diurnal
CARB	9.0	8.04	12.63	0.00	12.63
	9.5	9.33	14.06	0.00	14.06
	10.0	10.53	15.19	0.00	15.19
	10.5	11.65	16.01	0.00	16.01
	11.0	12.68	16.51	0.00	16.51
	11.5	13.63	16.70	0.00	16.70
FI	9.0	4.03	13.70	4.03	13.70
	9.5	5.18	15.51	5.18	15.51
	10.0	6.32	17.32	6.32	17.32
	10.5	7.47	19.07	7.47	19.07
	11.0	8.61	19.88	8.61	19.88
	11.5	9.76	20.20	9.76	20.20

---

* To be included in an upcoming EPA Technical Report, "The Effect of Fuel Volatility on Controlled and Uncontrolled Evaporative Emissions," by Celia Shih and Tom Darlington, TEB, ECTD, OMS, currently under development.

Table 2-B-7

85+ HDGV Tampering*

Uncontrolled Emission Rates (g/test)

RVP (psi)	Canister Removal		Cap Removal	
	Hot-Soak	Diurnal	Hot-Soak	Diurnal
9.0	14.67	26.08	3.69	26.08
9.5	16.40	28.83	3.91	28.83
10.0	18.12	31.59	4.26	31.59
10.5	19.86	34.35	4.75	34.35
11.0	21.58	37.11	5.36	37.11
11.5	23.31	39.87	6.11	39.87

Tampering Offsets (g/test)

RVP (psi)	Canister Removal		Cap Removal	
	Hot-Soak	Diurnal	Hot-Soak	Diurnal
9.0	10.98	22.39	0.00	22.39
9.5	12.49	24.00	0.00	24.00
10.0	13.86	25.12	0.00	25.12
10.5	15.11	25.75	0.00	25.75
11.0	16.22	25.88	0.00	25.88
11.5	17.20	25.53	0.00	25.53

---

* To be included in an upcoming EPA Technical Report, "The Effect of Fuel Volatility on Controlled and Uncontrolled Evaporative Emissions," by Celia Shih and Tom Darlington, TEB, ECTD, OMS, currently under development.

CHAPTER 3

Vehicle-Oriented Excess Evaporative HC Control

I. Introduction

This chapter will focus upon the modifications to current vehicular evaporative emissions control systems (ECSs) needed in order to improve their ability to control evaporative emissions. The need for such improvement stems from the proposed changes in the certification test procedure to: 1) eliminate the discrepancy between certification and in-use fuel volatility, and 2) begin the test with a fully saturated canister. These changes will necessarily require increased storage capacity and purge capacity in evaporative ECSs.

The key issues surrounding improvements of current evaporative ECSs involve the technological feasibility of potential modifications, and the costs associated with such modifications. These two issues are addressed in Sections II and III below, respectively. The overall conclusions are presented in Section IV.

Two effects that arise from improved evaporative ECSs that will affect the overall costs will be addressed separately from the generalized cost determination, as their costs are more of an indirect nature. These are: 1) an improvement in gas mileage due to increased fuel vapor recovery (i.e., the evaporative recovery/prevention credit), and 2) a reduction in gas mileage due to the extra weight involved in using a larger evaporative canister (i.e., the excess weight penalty). The former is addressed in Section VI of Chapter 4 and the latter in Appendix 6-B of Chapter 6. This chapter will focus primarily upon the initial price increase to the consumer.

II. Technology

As has been indicated, vehicular evaporative emissions control systems require modification in order to meet the stricter requirements imposed by the proposed changes in the certification test procedure. These changes will center around: 1) increasing the capacity of the canister to adsorb and desorb hydrocarbon vapors, and 2) increasing the ability of the control system to purge the evaporative canister. Before discussing the technological feasibility of making these improvements, however, it is necessary to understand what the system working capacity is, how it is determined, and to estimate how much more capacity is needed.

A. System Working Capacity

In Chapter 2 of this report, a brief description of system working capacity was presented. Therein, it was defined as the actual mass of gasoline vapors that an evaporative control system will adsorb and desorb during operation, and was described as being dependent upon factors both internal and external to the control system. That description will be expanded at this point.

The internal factors cited as determining, in part, the system working capacity are: 1) the physical characteristics of the charcoal, 2) the volume of charcoal in the canister, 3) the configuration of the canister, and 4) the volume of purge air drawn through by the control system.

Vapor adsorption and desorption is a purely physical process, with Van der Wall's bonding acting as the force holding the vapor to the charcoal.[1] The effectiveness of this bonding will depend upon the average particle size, the ratio of surface area to volume of the individual particles, and the size of the pores in which the vapor molecules are adsorbed. These various elements determine what is defined as the charcoal "working capacity" (measured as grams HC per 100 cubic centimeters (cc) of charcoal).

In a given volume of charcoal, smaller particles* can be compacted more tightly, thus increasing the likelihood that the vapors will come in contact with the surface of the particles. The tighter compaction of particles also allows for a greater mass of charcoal in a given volume, resulting in increased volumetric working capacity. This increase in charcoal working capacity has been seen in a designed experiment.[2] This same compaction, however, decreases permeability and reduces the flow rate through the canister at a specific pressure drop. It is for this reason that, in current practice, the maximum pressure drop across the canister at a specified flow rate is usually the determining factor in the selection of particle size.[3]

---

* Particle size of a given charcoal type is usually expressed in terms of mesh size and is expressed in the form A x B. A and B are divisions per inch and A x B size particles are able to pass through (1/A) inch by (1/B) inch openings. Thus, larger values of A and B represent a smaller mesh size and therefore smaller particles.

A greater surface area for a given particle implies more sites to which vapor molecules can be bonded. Therefore a particle with a highly convoluted surface having a large surface area to volume ratio will necessarily be a better adsorber than a particle of similar size with a smaller surface area to volume ratio. Increasing this ratio by disturbing the surface of a particle is the process that is referred to when carbon is defined as being activated.[4]

Finally, pore size can affect the charcoal working capacity, although the effect is not as clear as with particle size or the surface area-to-volume ratio. In general, vapor molecules will adsorb into pores of a size comparable to their own. It is possible, however, that larger particles can become lodged in pores in such a manner as to block access to more pore space that smaller particles could occupy. Since these larger particles are heavier and the bonding forces are stronger, they may not be removed during the purge cycle, and a portion of the carbon's adsorptivity will be lost.[1]

A charcoal's working capacity is measured as its ability to adsorb and desorb HC vapor, on a volumetric basis, under a relatively standardized test procedure. Working capacity is usually measured as grams of butane per 100 cc of charcoal, as butane is easy to work with, yields consistent results and is the dominant compound in vehicular evaporative emissions. Typical levels of "butane working capacity" for various charcoals are presented in Table 3-1. These values will not necessarily translate directly into charcoal working capacities for vehicular evaporative emissions, as these HC vapor mixtures are more complex than simple butane. Since HC species differ in their physical characteristics, they will be adsorbed preferentially and the degree of preference may depend upon carbon type. Thus, equal butane working capacities will not always result in equal gasoline working capacities.[2,4]

Assuming that the characteristics of the charcoal remain the same, there should be a direct relationship between the volume of charcoal used and the system working capacity. This should be clear from the definition of the charcoal working capacity.

Canister configuration may play a role in determining the system working capacity, although this fact is disputed. In a study by Scott Environmental Technology, the working capacity of a canister was increased by 12.3 percent by doubling the length of a cylindrical canister while holding the diameter, and therefore the cross sectional area, constant.[2] The theoretical explanation for this increase in working capacity

Table 3-1

Charcoal Properties*

Charcoal	Manufacturer	Base	Mesh Size	Surface Area (m^2/g)	Apparent Density (lb/ft^3)	Capacity (g/100 cc)	
						Test I*	Test II**
BPL-3	Calgon	Coal	6 X 14	800-1000	23-24	6.8	8.08
WV-A	Westvaco	Wood	10 X 25	1500-1700	15-18	8.5	8.31
WV-A	Westvaco	Wood	14 X 35	1600-1800	16-19	9.0	8.89
Extruded***	Westvaco	Wood	****	-----	20-21	10.5	--

---

* Specified by charcoal manufacturer in "Westvaco's Wood-Base Carbons Improve Evaporative Emission Control," Billy Kornegay, Ph.D., P.E., September 1980.

** From a test performed by Westvaco.

*** Data from phone conversation with Bill Kornegay of Westvaco Corporation on November 5, 1984.

**** Not specified, but equivalent pressure drop of mesh size 6 x 14.

centers on the concept of a "mass transfer zone" (MTZ). This theory states that when the carbon bed is charged, there will exist a zone which is fully saturated with hydrocarbons and a zone where the saturation decreases from fully saturated to completely devoid of hydrocarbons. This MTZ will only operate at half of its theoretical capacity when breakthrough occurs, and its length will not vary with the length of the carbon bed. A carbon bed whose length is twice that of the MTZ will have a capacity at breakthrough of 75 percent of maximum.* By doubling the length of the carbon bed, with the length of the MTZ remaining constant, there will be less under-utilization of capacity, and the capacity at breakthrough will be 87.5 percent of maximum.** This theoretical increase of 12.5 percent is quite close to that observed in the testing.[2]

Other reports, though, have indicated that system working capacity is not significantly related to canister configuration. The first of these provides no experimental results to support its conclusion, however. In the other, the only experimental results provided involved canisters that had been loaded beyond breakthrough, which is relevant with respect to total capacity, but not working capacity.[5] Thus, since the argument that there is no relationship between canister configuration and system working capacity appears quite flawed, whereas the argument for a relationship appears reasonable and consistent, working capacity must be considered to be sensitive to canister configuration.

The final factor that can be controlled by the evaporative emission control system designer is the volume of purge air drawn though the system. Without adequate purge, the carbon will saturate quickly and lose even more capacity that it would naturally. It has been shown that the total volume of purge air, rather than the velocity of the air, determines the amount of adsorbed hydrocarbon that will be desorbed.[3] When sufficient purge air is available, the system working capacity is the same as the "canister working capacity." Otherwise, it is less than the canister working capacity.

---

* Figured as: [0.5 (length) x 1.0 (capacity utilized)] +
[0.5 (length) x 0.5 (capacity utilized)].

** Figured as: [0.75 (length) x 1.0 (capacity utilized)] +
[0.25 (length) x 0.5 (capacity utilized)].

Chapter 2 also described several factors external to the control system that may affect the system working capacity. These include the humidity of the purge air, the temperature of the purge air, and the vapor concentration of the evaporative emissions. Working capacity will decrease with increased humidity, but this is not a lasting effect as charcoal has a higher affinity for hydrocarbons than for water vapor.[2] Working capacity will increase with higher temperature purge air as more HC can be desorbed at higher temperatures.[2,4] Working capacity will also increase when there is a larger concentration of HC vapors.[2] This latter effect is worth quantifying as it will become significant when in-use RVP and, therefore, HC vapor concentration, are changed.

The adsorptivity of charcoal has been found to be dependent upon the vapor concentration of the evaporative emissions.[2] This is illustrated in Figure 3-1, showing the average charcoal working capacities for two coal-based charcoals tested on 8.7 and 13.8 RVP (psi) fuels. The higher RVP fuel will necessarily produce a higher vapor concentration (due to its higher volatility) than the lower RVP fuel. The figure clearly shows an increase in charcoal working capacity with increasing RVP, which will translate into a higher system working capacity.

B. Extra Control Needed

The increase in system working capacity necessary to meet the requirements of the changes in the test procedure can be estimated by considering the resulting increase in uncontrolled emissions (i.e., HC vapors to the canister) that result from these changes. These must be adjusted, however, to reflect the changes in working capacity that will occur automatically without any modifications to the evaporative control system. The difference between these two will represent the amount of extra control that the ECS designer will have to develop.

Figure 3-2 shows graphically how the required amount of extra system working capacity is determined. Curve 1 shows the relationship between uncontrolled evaporative emissions and fuel volatility. Therefore, this curve represents the increase in system working capacity required with various RVP fuels. For present purposes, this curve has been normalized such that emissions from a 9.0 RVP fuel, typical of current certification fuel, equal 1.0. Curve 2 is a reproduction of Figure 3-1, showing the relationship between charcoal working capacity and fuel volatility. This curve has also been normalized such that the value for 9.0 RVP fuel equals 1.0. Curve 3 is the ratio of Curves 1 to 2, and indicates the additional system working capacity, relative to the 9.0 RVP baseline, that is needed in

FIGURE 3—1

CHARCOAL WORKING CAPACITY vs. RVP

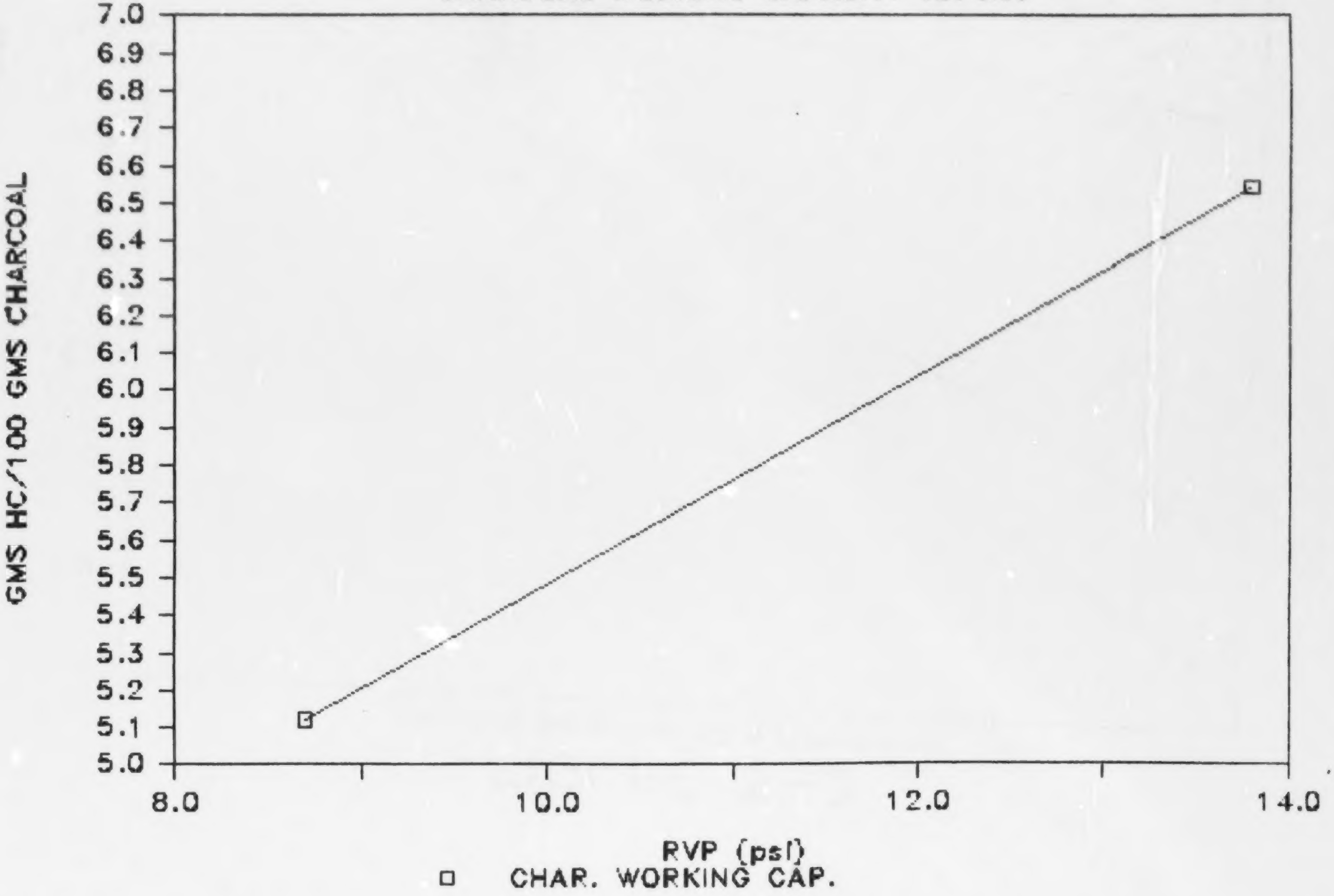
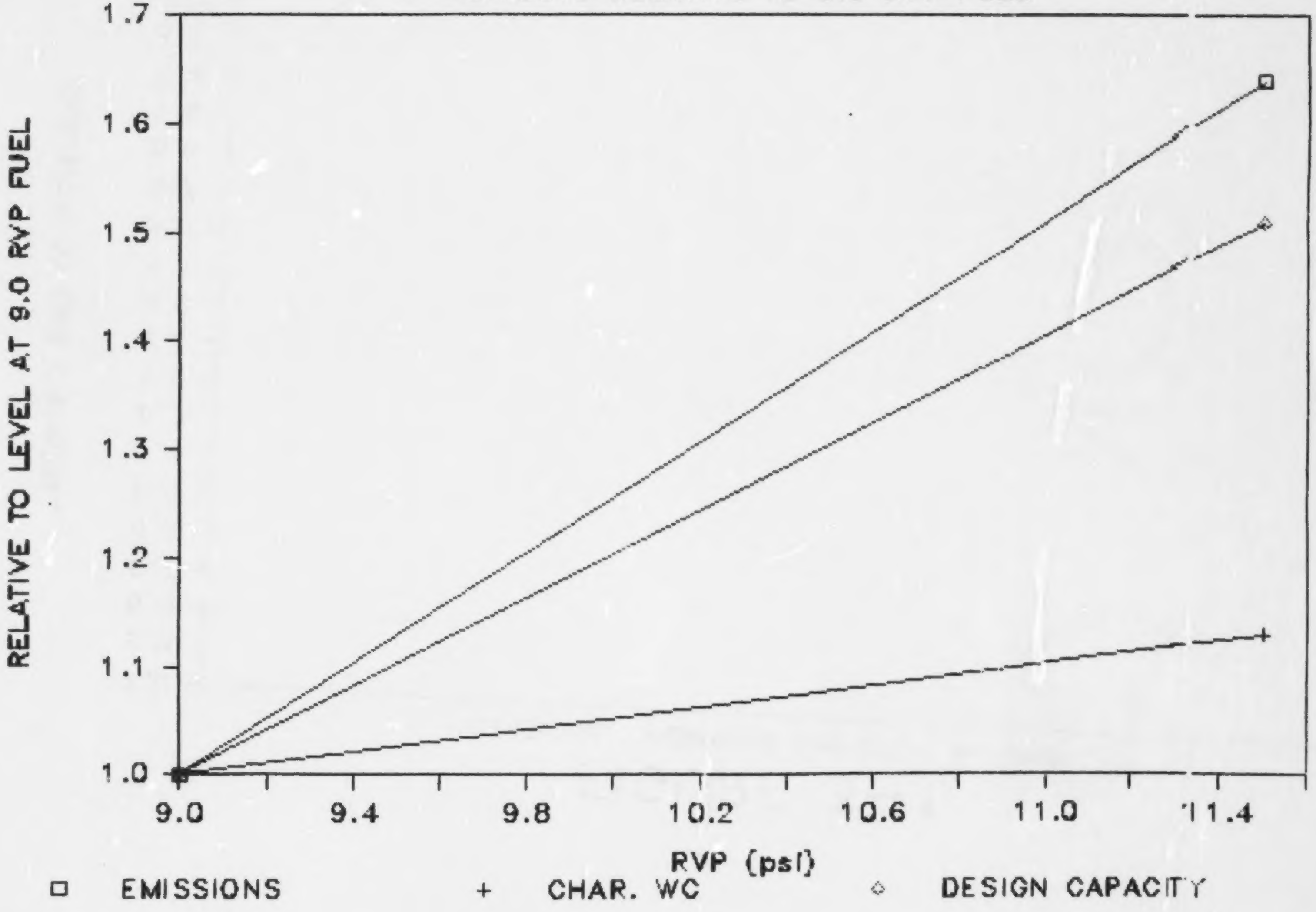


FIGURE 3—2

EFFECTS RELATIVE TO 9.0 RVP FUEL



addition to that naturally occurring within the system. For example, a change in the certification fuel to 11.5-psi RVP, while generating 64 percent more emissions, will only require the development of a 45-percent increase in system working capacity, as a 13-percent increase in the system working capacity will be realized from the increase in specific charcoal working capacity.

Because of the increase in the amount of uncontrolled emissions generated by a higher RVP fuel and loaded onto the larger capacity canister, a greater volume of purge air will be necessary to unload the canister during the purge cycle. With a higher RVP fuel, the HC concentration obtained in the vapor above the liquid fuel is greater than the HC concentration obtained with a lower RVP fuel. However, since the HC vapors are loaded at a higher HC concentration, and subsequently desorbed during the purge cycle at the same increased concentration, the purge volume only has to be increased by a degree that is less than the increase in uncontrolled emissions. Assuming the HC concentration is a linear function of RVP, the HC concentration to and from the canister with 11.5-psi RVP fuel is 28 percent greater than the HC concentration with 9.0-psi RVP fuel. Therefore, the purge volume only has to be increased by 28 percent (1.64/1.28 = 1.28) to purge an equal percentage of the adsorbed HC from the larger canister.

C. Potential Modifications

As discussed previously, to increase the system's capacity to control emissions, both canister capacity and purge air volume must be increased. Changing the canister configuration, increasing the desorption-adsorption temperature differential and changing the particle size are also options, but their effects are less pronounced and too vehicle-model specific to be considered here. The remainder of the discussion, then, will be limited to canister and purge capacity.

1. Canister Capacity

In order to increase the canister working capacity, either canister volume can be increased or specific charcoal working capacity can be increased. Though increasing the canister size will increase the cost of the evaporative emission control systems, it will require no significant technological innovation. The option of using a charcoal with a higher specific working capacity than that presently used has become technologically feasible for some systems with the introduction to the market in 1984 of a new type of charcoal. The properties of this "extruded" charcoal were shown in Table 3-1, along with the properties of other charcoals.

Because of the greater specific working capacity of the extruded charcoal (10.5 vs. 6.8-9.0 g/100 ml), canisters with an equal volume of the extruded charcoal would have a higher working capacity and, thus, be able to support emissions from a higher RVP fuel. This is shown in Table 3-2, taking into account the current carbon type of various manufacturers and curves 1 and 2 of Figure 3-2. By switching to this type of charcoal, then, present systems could support 9.7 - 11.7 RVP fuels without requiring an increase in canister size. An increase in pressure drop with the extruded charcoal may occur. However, the charcoal manufacturer expects to be able to accommodate these concerns by manufacturing various particle sizes.[6]

The option of switching to this extruded charcoal to meet an 11.0-11.5 RVP certification fuel standard is feasible for some vehicle manufacturers (i.e., those using large particle, coal-based charcoal). However, since it is not necessarily feasible industry-wide, the remainder of this report will consider only the alternative option to increase the canister capacity -- increasing the canister size. This is not meant to imply that charcoals with specific working capacities greater than those traditionally used could not be developed. It is more an indication of a decision not to make any assumptions about their development at this time. Also, in the absence of regulatory actions, improved charcoal could be used to reduce the volume of current canisters, thus still requiring an increase due to certification fuel and test procedure changes.

The increase in designed canister capacity required to meet a new RVP standard is shown in Table 3-3. For an 11.5 RVP certification fuel, this would be a 45-percent increase in carbon corresponding to: 580 ml for LDVs, 760 ml for LDTs and 1800 ml for HDVs. To estimate this for LDVs and LDTs, an average industry-wide canister size was determined from 1985 certification records by assuming an equal sales distribution between evaporative families for a given manufacturer and averaging corporate-average canister sizes by projected 1990 sales for each corporation. Only dominant manufacturers were included: General Motors, Ford, Chrysler, Toyota, and Nissan. For HDVs, an average canister size of 4000 ml is used, as it is expected that General Motors will use two canisters totaling 4000 ml of charcoal on all of its HDVs.[7] Details of these calculations are shown in Appendix 3-A.

It was assumed that all canisters would have to be proportionally increased in size to accommodate the increased emissions. Many manufacturers presently use identical canisters on vehicles with differing fuel tank sizes and fuel metering systems. The result is that many vehicles currently have oversized canisters. Presumably, it is more economically advantageous to overdesign some systems than to manufacture more than a few different-sizes of canisters. With the increasing use of fuel injection, though, there may be more

Table 3-2

Canister Equivalents With Extruded Charcoal

Canister	Present Carbon Type	Mesh Size	Ratio of Increased Working Capacity to Present Working Capacity	Equivalent RVP Control*
Ford	Calgon BPL-3	6 x 14	1.54	11.65
Chrysler	Westvaco WV-A	14 x 35	1.17	9.85
GM	Westvaco WV-A	10 x 25	1.24	10.20
Toyota**	Calgon BPL-3	6 x 14	1.54	11.65
Nissan**	Calgon BPL-3	6 x 14	1.54	11.65

---

* From Curve 3 of Figure 3-2.

** Estimated on the basis of charcoal type.

Table 3-3

Average Canister Volume Increase*

	Certification Fuel RVP (psi)									
	9.5		10.0		10.5		11.0		11.5	
Vehicle Class	ml	%	ml	%	ml	%	ml	%	ml	%
LDV	129	10	245	19	361	28	477	37	581	45
LDT	169	10	321	19	473	28	625	37	761	45
HDV	400	10	760	19	1120	28	1480	37	1800	45

---

* From curves 1 and 3 of Figure 3-2.

incentive to manufacture additional smaller canisters because of the lower emissions of fuel-injected vehicles. Thus, it is possible that the actual average canister volume increase required will be less than has been determined here.

It is also possible that some vehicle redesign may be required to physically accommodate a larger canister. Most canisters are presently installed in or adjacent to the engine compartment. It is assumed that there should be sufficient space to accommodate the larger canister, though it may not be as simple as replacing the existing canister. As was indicated earlier, switching to an improved charcoal is a possibility and this could be used to mitigate particularly difficult installations. Thus, no cost will be allocated for vehicle redesign in section III of this chapter.

2. Purge Capacity

Along with an increase in storage capacity, a similar increase in the ability to purge (e.g., desorb) the hydrocarbons from the canister will be required to handle the more volatile fuel. In addition, purge air may need to be increased to address the change in certification test procedure to begin with a saturated canister. This additional increase is likely for carbureted vehicles, since their current problem-free emissions on 9-psi RVP fuel are above the 2-gram standard (see Appendix 2-B). However, it should not be necessary for fuel-injected vehicles, since their analogous emissions are below the 2-gram standard.

Increasing the amount of purge can be accomplished either by increasing the duration of the purge or by increasing the rate of purge. The duration of purge can be increased by reducing the time during engine operation when purge does not occur in current systems. Currently, the first 2-3 minutes of engine operation and/or during minor deceleration are times during which many systems shut off the purge. The rate of purge, on the other hand, can be increased by increasing the size of the controlling orifice, thus allowing more air to be drawn through the canister in a given amount of time.

The primary concerns that arise with an increase in purge center upon vehicle performance. Increasing the purge will have an effect upon the engine's fuel-air ratio (absent feedback control), which in turn may have an effect upon exhaust emissions and engine performance. There exists the potential for increased HC and CO exhaust emissions, and negative effects upon driveability from rich misfire.

These concerns have been raised by engine manufacturers as they relate to the desired improvements in evaporative emission control, and also as they relate to the control of refueling emissions.[8,9] What little testing has been done addressing these concerns, however, has tended to indicate that these problems are not major and can be overcome fairly easily.

In 1978, the American Petroleum Institute (API) performed a series of tests on a carbureted closed-loop 1978 Pontiac Sunbird, modified to support a refueling emissions onboard control system. Though the amount of HC purged over an FTP increased by 65-86 percent, no significant increase in engine-out or post-catalyst emissions occurred, except in the extreme case where 77-91 grams of HC were purged in a single FTP. [10] This is well above that needed for evaporative HC control even at 11.5-psi RVP (i.e., 35-45 grams (see Table 2-B-6 in Appendix 2-B)). API's test results are summarized in Table 3-4. Driveability was evaluated in both cold-start and hot-start tests and was deemed excellent in both cases for the modified vehicle.[10]

Recently, API performed a series of FTP exhaust and evaporative emission tests on a multi-point fuel-injected 1985 Buick Century with a 9.0-psi RVP fuel and an 11.7-psi RVP fuel.[II] The results of the API testing show only slight increases in exhaust emissions because of the higher volatility of the test fuel. The comparison of results is made for a vehicle with a 400-ml carbon canister on the 9.0-psi RVP fuel, and the same vehicle with an 8-l onboard refueling carbon canister on the 11.7-psi RVP fuel. The amount of HC purged during the exhaust test portion on the enlarged canister was between 20-50 grams more than on the small canister, even though the purge rate was not changed. The HC emissions increased from 0.14 to 0.21 g/mi, the CO emissions increased from 1.81 to 2.30 g/mi, and the NOx emissions increased from 0.32 to 0.38 g/mi. However, these increases may not be statistically significant because of the limited number of tests performed on each fuel.

General Motors has done some testing on a 1981 4.3L V8 engine to determine the effects on exhaust emissions from an increase in the purge rate.[12] Only when the purge was increased to its maximum level (i.e., no restricting orifice), and then primarily when there was no delay before purge began (i.e., purge during cold operation when feedback system is inoperative), was there a significant increase in exhaust emissions to the point where current standards could not be met. (It is assumed that no delay indicates that for a period of time just after ignition the engine operated in an open-loop fashion.) GM's test are summarized in Table 3-5. There is no indication as to the effect that the increased purge rate had upon driveability.

Table 3-4

Effect of Purge on Exhaust Emissions [10]

Test No.	Canister	Canister HC Loading, g*	Purge		HC Purged, g	Exhaust Emissions, g/mi		
			Orifice, in.	Delay		HC	CO	NOx
----	Production Canister	50	0.100	-	26	0.39±0.03	6.41±0.91	0.98±0.07
1	4	160	0.180	3 min.	77	0.53	6.24	0.98
2	4	160	0.180	3 min.	91	0.49	6.43	0.84
3	5	160	0.125	3 min.	41	0.35	4.95	1.09
4	5	150	0.125	3 min.	56	0.38	5.45	0.99
5	5	160	0.125	No	67	0.41	6.28	0.96
6	5	160	0.125	No	74	0.42	7.34	0.93
7	6	160	0.100	30 sec.	23	0.33	5.88	0.93
8	6	160	0.100	30 sec.	18	0.41	6.85	1.01
9	6	160	0.090	No	22	0.36	6.02	1.04
10	6	160	0.090	No	19	0.35	5.63	0.99
11	6	160	0.110	No	25.9	0.39	5.91	1.01
12	6	0	0.110	No	1.0	0.37	6.35	1.03

---

* Refueling system canister.

** Average Emission Test Results

NOTE: Tests 1-6 used a purge valve drilled out to the orifice size specified. Tests 7-12 used a purge valve drilled to 0.180 in. with the specified orifice in-line.

Table 3-5

General Motors' Study of the Effect of Canister Purge Rate on Emissions - 1981 4.3L V8 [12]*

	Exhaust (g/mi)			Evap. HC (g/test)		
	HC	CO	NOx	DIU	HS	Total
Production	0.40	2.1	0.78	4.62	0.86	5.48
	0.41	2.5	0.78	3.53	0.82	4.35
	0.36	2.2	0.79	1.97	0.89	2.86
Max. Purge No Delay	0.66	8.1	0.66	0.59	0.72	1.32
	0.63	8.1	0.69	0.65	0.73	1.38
	0.53	5.9	0.73	0.52	0.67	1.18
Max. Purge	0.39	3.5	0.74	0.97	0.76	1.73
	0.38	4.7	0.71	0.86	0.81	1.66
	0.44	3.4	0.72	0.76	0.76	1.52
0.020 Constant Purge Orifice	0.44	2.1	0.76	2.04	0.93	1.97
	0.37	2.0	0.76	2.31	0.85	3.16
	0.40	2.5	0.73	2.00	0.79	2.79
0.040 Constant Purge Orifice	0.33	2.0	0.78	2.30	0.87	3.17
				2.82	0.81	3.63
				2.57	0.87	3.44
0.050 Constant Purge Orifice	0.38	2.2	0.78	2.54	0.86	3.40
	0.38	1.9	0.77	2.03	0.86	2.89
				2.14	0.78	2.92
				0.98	0.94	1.91
				2.27	0.88	5.15
0.060 Constant Purge Orifice	0.35	1.77	0.81	0.79	0.69	1.48
	0.45	2.25	0.88	1.62	0.88	2.50
	0.43	1.98	0.87	1.42	0.68	2.11
	0.40	1.05	0.90	2.45	0.89	3.34
	0.40	0.97	0.87	1.05	0.77	1.82
	0.37	1.01	0.91	0.47	0.83	1.30
0.070 Constant Purge Orifice	0.40	1.18	0.93	1.36	0.82	2.18
	0.37	1.53	0.88	1.36	0.89	2.26
	0.36	1.65	0.89	0.88	0.87	1.76
	0.38	1.40	0.91	1.91	0.77	2.69
	0.34	0.67	0.86	1.08	0.78	1.87
	0.35	1.96	0.89	1.30	0.92	2.22

---

* Prior to a 30-min. road prep (round-trip between Pontiac and Lake Orion, Michigan), the vehicle received a new carburetor, ECM, EGR, distributor, canister and converter.

Thus, it would appear that the problems posed by increasing the purge rate can be solved without significant effects upon vehicle performance. Closed-loop fuel metering control is expected to be present in 99 percent of light-duty vehicles sold in model years 1987 and beyond.[13] Also, naturally cleaner fuel-injected engines are projected to make up 89 percent of the light-duty gas vehicle and the light-duty gas truck market by model year 1990.[14] The presence of these two technologies will require that only small changes and some additional system calibration need be made to eliminate any measurable effects of increased purge upon vehicle performance.

Little information is currently available on evaporative ECSs for heavy-duty gas vehicles as they are just now being introduced. The systems used, however, are quite similar to those used in light-duty vehicles, with the necessary modifications in size. Thus, it is probable that the increased purge requirement can be met with fairly simple refinements to the control system.

III. Costs

This section will describe the method by which EPA has estimated the costs associated with the improvements in evaporative control technology discussed previously. Only the initial price increase to the consumer will be developed here. Operating costs, such as the weight-related fuel economy penalty and the credit due to recovered evaporative losses, are discussed in Appendix 6-B and Section VI of Chapter 4, respectively.

The costs of control are developed as they pass from the vendor to the vehicle manufacturer to the dealer and ultimately to the consumer. The ultimate cost to the consumer is referred to as the Retail Price Equivalent (RPE), and will include all of the increases seen along the way. It is this price increase which may potentially affect vehicle sales, which is addressed at the end of this section. All prices are presented in 1984 dollars, with adjustments from other years based upon the Bureau of Labor Statistics new consumer price index.*

---

* The 1984 new car CPI was estimated as 4 percent. This has now been determined by BLS to be 2.9 percent. This difference is not expected to significantly alter the conclusions of this analysis.

A. Vendor Level

In this particular case, "vendor" refers to the canister manufacturer, which may actually be the vehicle manufacturer in some cases. The need to build a larger canister and make adjustments to the purge system will lead to certain cost increases. These costs can be divided into: 1) a larger amount of carbon, 2) larger canister components, 3) retooling, and 4) the recalibration of the evaporative control system. The vendor will also include overhead (20 percent) and profit (20 percent) in the price that is passed on to the vehicle manufacturer.[15]

As the canister size increases, the amount of carbon required will increase with the volume of the canister. The increase required for a given certification fuel RVP was developed in the previous section and was summarized in Table 3-3. The carbon cost used is a vehicle-sales weighted average of the cost of the various types of carbon currently used by vehicle manufacturers. Table 3-6 shows the calculated costs for the increased carbon for each certification fuel RVP. These costs include the vendor overhead and profit mentioned previously. The details of these cost calculations, except for the markups for overhead and profit, are given in Appendix 3-A at the end of this chapter.

The canister components are assumed to increase in size in proportion to the increase in the total area of the canister. Therefore, they are treated separately from the carbon. The prices for the relevant components: the body, the grid, the filters, the caps, and the connectors have been taken from a 1983 draft report entitled, "Manufacturing Costs and Retail Price Equivalent of Onboard Vapor Recovery System for Gasoline-Filling Vapors," prepared by LeRoy Lindgren under contract to the American Petroleum Institute.*[16] This report has been reviewed in a previous document, and the costs have been modified slightly to correct for some arithmetic errors and discrepancies in markups for overhead and profit.[17] The calculations to determine the increased cost for each certification fuel RVP are detailed in Appendix 3-A, and the results are presented in Table 3-6. These include labor costs and markups for vendor overhead and profit. The latter were not included in the cost calculations in Appendix 3-A.

---

* This report has since been updated as the "Revised Report of API/LHI Cost Estimate of Onboard Vapor Recovery System and Review of EPA Technical Report EPA-AA-SDSB-84-01 on Feasibility, Cost, and Cost Effectiveness of Onboard Vapor Control," September 28, 1984. The costs cited here have not changed significantly, so this analysis has not been altered.

Table 3-6

Vendor Cost, Manufacturer Costs and Retail Price Equivalent Increases (1984 Dollars)

Vehicle Class		Certification Fuel RVP				
		9.5	10.0	10.5	11.0	11.5
LDV	Vendor Level Costs:					
	Carbon*	.20	.40	.59	.79	.99
	Canister*	.15	.20	.27	.32	.38
	Tooling	.08	.08	.08	.08	.08
	ECU	.07	.07	.07	.07	.07
	Total Vendor Level Costs	.50	.75	1.01	1.26	1.52
	Manufacturer Level Costs:					
	RD&T	.07	.09	.10	.12	.13
	Certification	.60	.60	.60	.60	.60
	Total Manuf. Level Cost	1.17	1.44	1.71	1.98	2.25
	Manuf. Overhead/Profit**	.28	.35	.41	.48	.54
	Total Dealer Cost	1.45	1.79	2.12	2.46	2.79
	Dealer Profit***	.05	.05	.07	.07	.09
	Retail Price Equivalent	1.50	1.84	2.19	2.53	2.88
LDT	Vendor Level Costs:					
	Carbon*	.27	.55	.83	1.10	1.38
	Canister*	.16	.25	.33	.40	.46
	Tooling	.08	.08	.08	.08	.08
	ECU	.07	.07	.07	.07	.07
	Total Vendor Level Costs	.58	.95	1.31	1.65	1.99
	Manufacturer Level Costs:					
	RD&T	.13	.16	.18	.20	.23
	Certification	.76	.76	.76	.76	.76
	Total Manuf. Level Cost	1.47	1.87	2.25	2.61	2.98
	Manuf. Overhead/Profit**	.35	.45	.54	.63	.72
	Total Dealer Cost	1.82	2.32	2.79	3.24	3.70
	Dealer Profit***	.06	.07	.09	.10	.10
	Retail Price Equivalent	1.88	2.39	2.88	3.34	3.80
HDV	Vendor Level Costs:					
	Carbon*	.34	.69	1.03	1.39	1.71
	Canister*	.28	.45	.60	.73	.84
	Tooling	.08	.08	.08	.08	.08
	ECU	.07	.07	.07	.07	.07
	Total Vendor Level Costs	.77	1.29	1.78	2.27	2.70
	Manufacturer Level Costs:					
	RD&T	.32	.38	.45	.52	.58
	Certification	-	-	-	-	-
	Total Manuf. Level Cost	1.09	1.67	2.23	2.79	3.28
	Manuf. Overhead/Profit**	.26	.40	.54	.67	.79
	Total Dealer Cost	1.35	2.07	2.77	3.46	4.07
	Dealer Profit***	.05	.07	.08	.09	.13
	Retail Price Equivalent	1.40	2.14	2.85	3.57	4.20

---

* Prices include 40 percent vendor mark-up for overhead and profit.

** A mark-up of 24 percent was used for corporate overhead and profit.

*** A mark-up of 3 percent was used for dealer profit.

Retooling costs will also be incurred by the canister manufacturer. Total tooling costs are specified by Lindgren as $0.16 per canister.[16] Complete retooling will not be required, though, since current canister sizes will still be appropriate for many vehicles. Thus, it is assumed that the tooling cost associated with an increase in canister size will be approximately half of this cost, or $0.08 per canister. This is also summarized in Table 3-6. For an 11.5-psi RVP certification fuel, the total per-vehicle component cost to the vehicle manufacturer is $1.52 for LDVs, $1.99 for LDTs and $2.70 for HDVs.

As it was previously determined that increasing the purge rate would only require recalibration of existing systems, no new hardware need be costed out. However, a $.07 per-vehicle cost is allocated to modify existing electronic control units (ECUs). This cost is the same as that assumed necessary to modify existing ECUs to accommodate an onboard refueling vapor control system.[18]

The sum of the above costs represent the total vendor level costs, which are then passed on to the vehicle manufacturer. However, where the canister manufacturer is the same as the vehicle manufacturer, as it is in many cases here, this is primarily a transfer cost.

B. Manufacturers Level

The vehicle manufacturer must purchase (or transfer) the canister and control technology at the vendor level cost rate. The manufacturer will also face research, development, testing, and certification costs associated with the implementation of the improved technology. There are also corporate overhead and profit that are incorporated into the price that is passed on to the dealer.

Research, development, and testing costs will be incurred by the manufacturer to recalibrate the fuel metering and emission control systems. As it was determined that this would require no additional hardware (the only hardware modification -- the ECU -- being addressed previously), this cost will include only design modification and testing costs.

Estimates for these costs are difficult to determine. It will be assumed here that, on average, for an 11.5-psi RVP certification fuel standard, 25 vehicle tests, 2 months of technician time and 1 month of engineering will be sufficient to recalibrate each engine-evaporative family combination. Testing costs for LDVs and LDTs were obtained from earlier EPA work on light-duty certification costs.[19] For HDVs, the cost used here was that determined in the previous HDE rulemaking which instituted HDV evaporative HC controls.[20] It is further assumed that this cost is proportional to the control required. A vehicle acquisition cost, held constant for all levels of control, is also included.[17] This methodology is detailed more in Appendix 3-A.

The research, development and testing costs (RD&T) are summarized in Table 3-6. These have been amortized over 5 years at 10 percent to reflect the spreading out of payments by the manufacturer. For an 11.5-psi RVP certification fuel, this yields $.13/vehicle for LDVs, $.23/vehicle for LDTs and $.58/vehicle for HDVs.

Manufacturers of LDVs and LDTs will incur a cost to certify their fleets with a new certification fuel. No recertification cost will be incurred by HDV manufacturers, because no formal evaporative testing is required by EPA (the development testing previously discussed should be sufficient). The LDV/LDT costs were obtained from the EPA work previously cited.[17] Because year to year carryover of engine families is not 100 percent, only 90 percent of the LDV/LDT recertification costs would be attributable to this change. Amortization over 5 years at 10 percent results in a $.60/vehicle LDV and $.76/vehicle LDT cost impact (see Appendix 3-A for details).

Before passing on the cost to the dealer, the vehicle manufacturer will add markups for corporate overhead and profit. These were determined to be 10 percent and 14 percent, respectively, in an earlier EPA cost analysis.[21] These markups are applied to the sum of the total vendor level costs, the research and development costs, and the certification costs. This value is shown in Table 3-6.

The total cost at the manufacturer level, then, is the sum of the hardware, development, certification, and markup costs. It is assumed that no significant retooling will be required at the assembly level -- only at the canister manufacturing level.

C. Dealer Level

The total increase in cost seen by the dealer is shown in Table 3-6. The dealer is expected to make a reasonable profit from the sale of a vehicle. Therefore, a markup which recovers incremental costs and yields a fair return on incremental investment must be included in the total cost. This markup was determined to be 3 percent in the same EPA cost analysis used to determine corporate overhead and profit. [15] The dealer markups in each situation are shown in Table 3-6.

D. Consumer Level (Retail Price Equivalent)

The bottom line of Table 3-6 shows the increase in initial cost expected to be seen by the consumer. The resulting RPE increase associated with a change to an 11.5-psi RVP certification fuel is $2.88/vehicle for LDVs, $3.80/vehicle for LDTs, and $4.20/vehicle for HDVs.

E. Impact on Vehicle Sales

The impact on vehicle sales due to the retail price equivalent increase is determined by the price elasticity of demand. For light-duty vehicles and trucks, this is approximately -1.0 and for heavy-duty trucks it is in the range of -0.9 to -0.5.[17,22] For the purposes of this analysis, a -0.7 price elasticity will be assumed for HDVs. This means, for the HDV case, that a 1-percent increase in the RPE should result in a 0.7-percent decrease in demand.

Prices for light- and heavy-duty vehicles vary considerably. Using an average light-duty vehicle and truck cost of $10,000 and a heavy-duty vehicle cost range of $11,000-57,000 results in the vehicle demand decrease shown in Table 3-7 for an 11.5 RVP certification fuel (2250-2790 LDVs, 940-1110 LDTs and 140-170 HDVs). With price decreases of this small magnitude, though, the use of this price/demand impact model is questionable. This price increase would probably be of little consequence in relation to annual price increases occurring at the time of new model year introduction. In any event, the sales impacts estimated by the model are negligible.

IV. Conclusions

The improvements required to increase storage capacity and purge capacity in vehicular ECUs appear to be feasible with current technology. No significant effects upon vehicle performance other than reduced evaporative emissions are expected from these changes. The final cost to the consumer at the time of vehicle purchase has been estimated as $2.88/vehicle, $3.80/vehicle, and $4.20/vehicle for LDVs, LDTs, and HDVs, respectively, in the most extreme case of an 11.5-psi RVP certification fuel. These cost increases are not expected to impact upon vehicle sales to any significant degree.

Table 3-7

Vehicle Demand Impact with an 11.5 RVP Certification Fuel

Vehicle Class	Percent Price Increase	Percent Demand Decrease	Number Demand Decrease*
LDV	0.021-0.026	0.021-0.026	2254-2791
LDT	0.032-0.038	0.032-0.038	938-1114
HDV	0.045-0.053	0.032-0.037	145-167

---

* Uses 1990 vehicle sales projections.

References (Chapter 3)

1. "Basic Concepts of Adsorption on Activated Carbon," Activated Carbon Division, Calgon Corporation.

2. "Control Characteristics of Carbon Beds for Gasoline Vapor Emissions," EPA-600/2-77-057, Michael J. Manos and Warren C. Kelly, Scott Environmental Technology, Inc. for EPA, ORD, IERL, February 1977.

3. "Activated Carbon for Effective Control of Evaporative Losses," Ronald S. Joyce, Paul. D. Langston, George R. Stoneburner, Charles B. Stunkarol, and George S. Tobias, Pittsburgh Activated Carbon Division, Calgon Corp., SAE Paper #690086, January 1969.

4. Meeting with Howard Shrut, Calgon Corporation, July 18, 1984.

5. "Combustion Engine Economy, Emissions and Control July 18-12, 1985," The University of Michigan, College of Engineering, Ann Arbor, MI.

6. Conversation with Bill Kornegay, Ph.D., Technical Director, Chemical Division, Westvaco Corporation, November 5, 1984.

7. "Characterization of Fuel/Vapor Handling Systems of Heavy-Duty Gasoline Vehicles over 10,000 Pounds GVW," Draft Report, prepared by Jack Faucett Associates for EPA, OMS, Contract No. 68-03-3244, September 27, 1985.

8. Comments of the Motor Vehicle Manufacturers Association of the United States, Inc., on EPA Report 450/3/84-012a, "Evaluation of Air Pollution Regulatory Strategy for Gasoline Marketing Industry," November 8, 1984. (Available in Public Docket No. A-84-07.)

9. Comments on EPA Report 450/3/84-012a, "Evaluation of Air Pollution Regulatory Strategy for Gasoline Marketing Industry," submitted by Chrysler Corporation to U.S. EPA, November 5, 1984. (Available in Public Docket No. A-84-07.)

10. "Onboard Control of Vehicle Refueling Emissions: Demonstration of Feasibility," API Publication No. 4306, October 1978.

11. "API Onboard Refueling Emission Control Project," work by Mobil Research and Development Corporation, presentation to EPA-ECTD, August 7, 1985.

References (Chapter 3) Cont'd

12. General Motors Submittal to EPA, March 11, 1985 (letter from Eric O. Stork, Deputy Assistant Administrator for Mobile Source Air Pollution Control, EPA, to Thomas M. Fisher, General Motors, dated September 3, 1976).

13. "Emission Control Technology and Strategy for Light-Duty Vehicles 1982-1990. Final Report," prepared by Energy and Environmental Analysis, Inc.

14. "Automotive Technological Projections Based on USA Energy Conservation Policies," Dana Jones and LeRoy Lindgren, December 17, 1983.

15. "Cost Estimations for Emission Control Related Components/Systems and Cost Methodology Description," EPA-460/3-78-002, U.S. EPA, March 1978.

16. "Manufacturing Costs and Retail Price Equivalent of Onboard Vapor Recovery System for Gasoline Filling Vapors," LeRoy Lindgren under contract to API, June 1983. (Attachment to MVMA Comments, Reference 8, available in Public Docket A-84-07.)

17. "The Feasibility, Cost, and Cost Effectiveness of Onboard Vapor Control," EPA-AA-SDSB-84-01, Glenn W. Passavant, U.S. EPA, March 1984.

18. "Costs of Onboard Vapor Recovery Hardware," Mueller Associates under sub-contract to Jack Faucett under contract to EPA, February 14, 1985.

19. "Light-Duty Vehicle Certification Cost," memo to Edmund J. Brune, Director, Certification and Surveillance Division from Daniel P. Hardin, Jr., Certification and Surveillance Division Staff, U.S. EPA, March 13, 1975.

20. "Regulatory Analysis and Environmental Impact of Final Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines," EPA, OMSAPC, December 1979. (Available in Public Docket No. OMSAPC-78-4.)

21. See for example the Regulatory Analysis and Summary and Analysis of Comments prepared in support of the light-duty diesel particulate regulations for 1982 and later model year light-duty diesel vehicles. (Both are available in Public Docket No. OMSAPC78-3.)

22. "Regulatory Support Document for the Final Evaporative Emission Regulation and Test Procedure for 1984 and Later Model Year Gasoline-Fueled Heavy-Duty Vehicles," EPA/OAR/OMS, January 1983. (Available in Public Docket No. OMSAPC-79-1.)

Appendix 3-A

Detailed Derivation of Evaporative ECS Component Costs

This appendix details the calculations used to derive the evaporative emission control system (ECS) costs discussed in Chapter 3. The first section will describe how the average canister sizes for current evaporative control systems were determined. This will be followed by sections discussing: 1) canister material costs, 2) research, development and testing costs, and 3) certification costs associated with the changes in the certification test procedure.

Average Canister Sizes in Current Vehicles

The average canister sizes for current vehicles were calculated by using a sales-weighted average of the canister sizes currently in use. Only the major manufacturers -- GM, Ford, Chrysler, Toyota, and Nissan -- were considered in this calculation.

Table 3-A-1 shows the canister sizes used by each manufacturer for various engine families. Table 3-A-2 combines these values into a single value for light-duty vehicles and light-duty trucks for each manufacturer, assuming equal sales per engine family. Using the forecasted 1990 normalized market share shown in Table 3-A-3 for these five manufacturers, a sales-weighted average canister size for each vehicle class is determined. These industry-wide average canister sizes are summarized in Table 3-A-4. As indicated in the table, the average canister size for heavy-duty gas vehicles is taken as the current size for GM vehicles, as GM dominates this market (i.e., two-thirds of sales).

Canister Material Costs

This section details the methodology used to determine the costs associated with improving canister working capacity. These costs will be determined for each potential certification fuel RVP.

Table 3-A-5 shows the canister material costs to vendors taken from a draft report prepared for API by LeRoy Lindgren.* The costs presented are for an 850 ml GM canister, which is smaller than the average canister sizes for current LDV, LDT and HDV classes shown in Table 3-A-4.

---

*Reference 16 in Chapter 3. A final version of the report has since become available, but the changes were not significant so the calculations were not redone.

Table 3-A-1

Canister Distribution

Manufacturer	Canister Size (ml)	Number of Families LDV*	LDT*
GM	1500	29	2
GM	2500	-	5
GM	2500 + 300	-	1
GM	2500 + 1500	-	0
Ford	925	7	8
Ford	1400	3	7
Ford	1400 + 1400	1	-
Chrysler	1320	4	1
Chrysler	1790	3	6
Chrysler	1320 + 1320	-	4
Toyota	835	2	1
Toyota	845	1	-
Toyota	1400	1	1
Toyota	1400 + 645	-	1
Nissan	580	6	3
Nissan	1230	2	-

---

* 1983 Model Year

Table 3-A-2

Average Canister Size by Manufacturer

Vehicle Class	Manufacturer	Avg. Canister Size for 9.0 RVP Fuel (ml)*
LDV	GM	1500
LDV	Ford	1225
LDV	Chrysler	1521
LDV	Toyota	979
LDV	Nissan	743
LDT	GM	2288
LDT	Ford	1147
LDT	Chrysler	2059
LDT	Toyota	1427
LDT	Nissan	580

---

* Average of 1983 MY canisters assuming equal sales of evap. families.

Table 3-A-3

Market Shares by Manufacturer

Vehicle Class	Manufacturer	1983 Normalized* Market Share (%)	1990 Normalized** Market Share (%)
LDV	GM	45.74	46.81
LDV	Ford	17.78	18.20
LDV	Chrysler	9.56	9.78
LDV	Toyota	13.89	13.00
LDV	Nissan	13.03	12.21
LDT	GM	41.98	40.86
LDT	Ford	34.76	33.84
LDT	Chrysler	10.12	9.85
LDT	Toyota	7.29	8.57
LDT	Nissan	5.85	6.88

---

* Normalized on the basis of 100 percent of the domestic LDV and LDT market is shared by GM, Ford and Chrysler, and 100 percent of the imported LDV and LDT market is shared by Toyota and Nissan.

** Normalized as for 1983. Manufacturers' shares of domestic or imported market is assumed to be the same as for 1983, but the ratio of imported to domestic registrations changed in accordance with projections made in Reference 13 of Chapter 3.

Table 3-A-4

Industry-Wide Average Canister Size*

Vehicle Class	Avg. Canister Size for 9.0 RVP Fuel (ml)
LDV	1292
LDT	1688
HDG	4000**

---

* Uses 1989 Market Shares.

** Average canister size used by GM.

Table 3-A-5

Canister Material Cost to Vendor (Dollars)*

Component Description	Material	Weight (lbs.)	Material Costs ($)**
Body	DB437	.30	.25
Grid	G7	.10	.04
Int. Filter	AY332	.10	.10
Ext. Filter	KZI-4	.20	.21
Charcoal	54448	.50	.50
Cap	DB437	.10	.08
Connectors	DB437	.05	.04
TOTAL			1.22

---

* Taken from Reference 16 of Chapter 3.

** Material costs are those for an 850-ml GM canister and were converted to 1984 dollars from 1983 dollars.

Table 3-A-6 shows these material costs after they have been scaled up to the average canister sizes for LDV, LDT and HDV families. The charcoal costs were increased in proportion to the increase in volume of the canisters. The body, grid, filter and cap costs were increased in proportion to the increase in surface area of the canister. (For cylinders which have the same length-to-diameter ratio, the ratio of surface areas is equal to the ratio of volumes to the two-thirds power.) The connector cost is independent of the canister size and therefore remains constant.

The charcoal costs per unit volume were calculated on a 1990 vehicle sales-weighted basis (See Table 3-A-3). GM and Chrysler use wood-based charcoals (price = $1/lb, density = .26-.30 g/ml) whereas Ford, Nissan, and Toyota use coal-based charcoals (price = $2/lb., density = .37-.38 g/ml). Tables 3-A-7, 3-A-8, and 3-A-9 contain the canister material cost increases to meet a higher RVP certification fuel for LDV, LDT and HDV classes, respectively. The increases in volume required for each higher RVP certification fuel are listed in Table 3-3 of Chapter 3 and the increases in surface area can be determined from the volume ratios (as stated earlier). The increases in costs were calculated by exactly the same method as was used to scale up the 850-ml GM canister to the average canister sizes for each class of vehicle.

Research, Development and Testing Costs

Table 3-A-10 contains a summary of the research, development and testing (RD&T) costs for a change in certification fuel to an RVP of 11.5 psi. The various costs of RD&T per engine family are broken down in Table 3-A-10 and costs for each component were estimated using engineering judgment. The total cost was calculated using the total number of engine families from 1984 certification records. The total cost was amortized at 10 percent for five years and this amount was used to determine the cost per vehicle based upon 1989 sales projections.

To obtain the costs for a change in the certification fuel to an RVP between 9.0 psi and 11.5 psi, the vehicle modification costs were held constant and the salary and testing costs were varied linearly. The RD&T costs for the different certification fuels are listed in Table 3-6 of Chapter 3.

Table 3-A-6

Baseline* Canister Material Costs to Vendor (1984 Dollars)

Component Description	Vehicle Class LDV	 LDT	 HDV
Body	.33	.39	.70
Grid	.05	.06	.11
Int. Filter	.13	.16	.28
Ext. Filter	.28	.33	.59
Charcoal**	1.39	1.92	2.40
Cap	.11	.13	.22
Connectors	.04	.04	.04
TOTAL	2.33	3.03	4.34

---

* Baseline refers to the average canister sizes for 9.0 RVP fuel shown in Table 3-A-4.

** Charcoal cost is the 1990 sales-weighted average cost of the different types of charcoals (in 1984 dollars). Wood-based charcoal ($1/lb) is used by GM and Chrysler and coal-based charcoal ($2/lb) is used by Ford, Nissan, and Toyota.

NOTE: Body, filter, grid, and cap costs increase in proportion to the surface area and charcoal cost increases in proportion to the volume. (Canister length-to-diameter ratio is assumed to remain constant.) Connector cost is independent of the canister volume, thus there is no increase in material cost to the vendor for connectors for larger canisters.

Table 3-A-7

LDV Canister Material Cost Increase at Vendor Level* (1984 Dollars)

Component Description	Certification Fuel RVP (psi)				
	9.5	10.0	10.5	11.0	11.5
Body	.02	.04	.06	.08	.10
Grid	.00	.01	.01	.01	.02
Int. Filter	.01	.02	.03	.03	.04
Ext. Filter	.02	.04	.05	.07	.09
Charcoal	.14	.28	.42	.56	.71
Cap	.01	.01	.02	.03	.03
TOTAL	.20	.41	.59	.78	.99

---

* Does not include 40-percent vendor mark-up for overhead and profit.

Table 3-A-8

LDT Canister Material Cost Increase at Vendor Level* (1984 Dollars)

Component Description	Certification Fuel RVP (psi) 9.5	10.0	10.5	11.0	11.5
Body	.03	.05	.08	.10	.12
Grid	.00	.01	.01	.01	.02
Int. Filter	.01	.02	.03	.04	.05
Ext. Filter	.02	.04	.06	.08	.10
Charcoal	.19	.39	.59	.79	.98
Cap	.01	.02	.03	.03	.04
TOTAL	.26	.53	.80	1.06	1.31

---

* Does not include 40-percent vendor mark-up for overhead and profit.

Table 3-A-9

HDV Canister Material Cost Increase at Vendor Level* (1984 Dollars)

Component Description	Certification Fuel RVP (psi) 9.5	10.0	10.5	11.0	11.5
Body	.05	.09	.14	.18	.22
Grid	.01	.01	.02	.03	.03
Int. Filter	.02	.04	.05	.07	.09
Ext. Filter	.04	.08	.11	.15	.19
Charcoal	.24	.49	.74	.99	1.22
Cap	.01	.03	.04	.06	.07
TOTAL	.37	.74	1.10	1.48	1.82

---

* Does not include 40-percent vendor mark-up for overhead and profit.

Table 3-A-10

Research, Development and Testing (RD&T) Costs Summary (1984 Dollars)

LDV/LDT: ($/family)

Vehicle Modification	16,000[1]
Engineer Salary (1 mo. @ $50K/yr)	4,170[2]
Technician Salary (2 mo. @ $35K/yr)	2,920[2]
25 Tests (@ $610/test)[1]	15,250
	38,340

HDV: ($/family)

Vehicle Modification	20,000[2]
Engineer Salary (1 mo. @ $50K/yr)	4,170[2]
Technician Salary (2 mo. @ $35K/yr)	2,920[2]
25 Tests (@ $2000/test)[3]	50,000
	77,090

	LDT	LDT	HDV
Cost/Family	$38,340	$38,340	$77,090
Number of Families	137[4]	81[4]	11[3]
Total Cost	$5,252,580	$3,105,540	$847,990
5 years @ 10%	$1,385,629/yr	$819,241/yr	$223,700/yr
1989 Sales	11,000,000[5]	3,640,000[5]	386,000[3]
RD&T Cost/Vehicle ($)	0.13	0.23	0.58

---

[1] Inflation-adjusted values from EPA memo, "Light-Duty Vehicle Certification Cost," from Daniel P. Hardin, March 13, 1975. [Reference 19 of Chapter 3.]

[2] Estimated.

[3] "Regulatory Impact Analysis, Oxides of Nitrogen Pollutant Specific Study and Summary and Analysis of Comments," EPA, March 1985.

[4] EPA's "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Federal Certification Test Results for 1984 Model Year."

[5] Based on DRI "trendlong" projections from the Fall 1984 Long-Term Review, Data Resources Inc., 1984.

Certification Costs

Table 3-A-11 contains a summary of the certification costs associated with a new certification fuel. The costs per vehicle tested are summarized for both emissions data and durability vehicles. The total costs are based on the number of LDVs and LDTs certified in 1984. However, only those engine families which are carried over from the previous year are relevant, since those which are recertified anew would experience certification costs with or without a new certification fuel. Carryover is estimated to be 90 percent; therefore, the total cost was reduced to 90 percent of its original value. The reduced total was amortized at 10 percent for five years and this amount was used to determine the cost per vehicle based upon 1989 sales projections. It should be noted that formal certification testing for evaporative emissions is not required for HDVs. Thus, there is no certification cost associated with a change in the HDV certification fuel.

Table 3-A-11

Certification Costs Summary (1984 Dollars)

Emission Data Vehicle Costs:[1] ($/Vehicle Tested)

Vehicle Modification	16,000
Mileage and Maintenance (@ $2.60/mile, 4000 miles)	10,400
Testing Cost (2 Tests/Vehicle, $610/test)	1,220
	27,620

Durability Vehicle Costs:[1] ($/Vehicle Tested)

Vehicle Modification	16,000
Mileage and Maintenance (@ $3.09/mile, 50,000 miles)	154,500
Testing Cost (13 Tests/Vehicle, $610/test)	7,930
	178,430

Total Vehicles Tested and Costs: ($)

	LDV	LDT
Emission Data (307 LDV, 133 LDT)[2]	8,479,340	3,673,460
Durability (109 LDV, 45 LDT)[2]	19,448,870	8,029,350
Total Cost	27,928,210	11,702,810
90% Carryover	$25,135,389	$10,532,529
5 yrs. @ 10%	$6,631,200	$2,779,000
1989 Sales[3]	11,000,000	3,640,000
Certification Cost/Vehicle ($)	0.60	0.76

---

[1] Inflation-adjusted values from EPA memo, "Light Duty Vehicle Certification Cost," from Daniel P. Hardin, March 13, 1975. [Reference 19 of Chapter 3.]

[2] EPA's "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Federal Certification Test Results for 1984 Model Year."

[3] Based on DRI "trendlong" projections from the Fall 1984 Long-Term Review, Data Resources Inc., 1984.

CHAPTER 4

Technological Feasibility and Cost of In-Use Gasoline Volatility Control

I. Introduction

As described in Chapter 2, one of the two possible methods of eliminating the current evaporative emission excess is to control the volatility of commercial gasoline. Estimates of refinery costs and fuel economy benefits of reducing in-use gasoline volatility are presented in this chapter. As also described in Chapter 2, the two fuel parameters most relevant to evaporative emissions are RVP and $\%_{160}$. In-use control of both of these parameters is being considered. However, the great majority of the refinery modelling performed thus far has focused on the control of RVP, as the effect of this parameter on evaporative emissions is most well known. Studies of the cost of controlling $\%_{160}$ are still underway, though the results available to date are presented in Section III.C below.

This chapter begins with a general discussion of gasoline volatility and the types of HC compounds which most affect it (Section II). The next section (Section III) presents a general description of the main source of information for the cost of in-use gasoline RVP control and $\%_{160}$ control, a study conducted by Bonner and Moore Management Science for EPA.[1] This study uses their proprietary Refinery and Petrochemical Modeling System (RPMS), which is a linear programming (LP) computer model. This section also presents the results of the Bonner and Moore study, primarily the refinery cost of reducing gasoline RVP one to two psi below ASTM limits under various situations, but also includes the cost of reducing $\%_{160}$ to 25 or 30 percent. Section IV examines the effect of RVP control (and the likely butane excess generated by it) on the wider butane market. Section V examines the effect of RVP control on the energy content of gasoline and estimates the resultant effect on vehicular fuel economy. Section VI examines the additional economic benefit of recovering or preventing evaporative emissions (via both fuel- and vehicle-related controls) from both vehicles and the distribution system. Section VII combines the results of the previous sections to evaluate the overall cost of volatility control of in-use gasoline.

II. Refinery Control of Gasoline Volatility

Oil refineries currently refine crude oil to supply several petroleum products, one of which is gasoline for motor vehicle consumption. The volatility of the gasoline produced depends on the properties of the crude oil and the natural gas liquids (NGLs), which include butanes and natural gasoline, used in the refining process and on the actual refining processes themselves. There are ASTM specifications for gasoline volatility characteristics which serve as guidelines for the refineries to follow. These ASTM gasoline volatility specifications and in-use volatility trends were already described in Chapter 2, Section IV.

As already mentioned, RVP and $\%_{160}$ are the two most important gasoline volatility properties affecting evaporative HC emissions. The major HC compounds contributing to high RVP are n-butane and iso-butane, although n-pentane and iso-pentane also affect RVP. The RVP blending values for these parafins are given in Table 4-1. Generally, the easiest way to reduce gasoline RVP is to reduce the blending of straight butane into gasoline. The next easiest approach is to remove butane presently contained in other gasoline stocks. This requires modification of existing separation facilities and/or the installation of new facilities to remove contained butanes. In addition, butane can be converted, via processes such as alkylation, in higher boiling compounds. As a further step, extreme RVP limits could require removal of some C_5 components which, in most cases, would require new separation facilities. The approach that is actually used depends on the economics involved, which are complex and highly interactive.

Both butanes and pentanes strongly affect $\%_{160}$, but so do many other gasoline components, and the specific relationship between each of these components and $\%_{160}$ is beyond the scope of this study. Suffice it to say that the more short-chain hydrocarbons (with four to five carbon atoms) in gasoline, the higher the RVP and $\%_{160}$.

Butane has a high-octane quality. Thus, RVP control which reduced the use of butane would also require additional refinery processing to compensate for the octane quality which the butane would otherwise provide.

The use of alcohols in gasoline complicates matters, since both methanol and ethanol affect RVP as well as other volatility parameters and octane. Their RVP blending values are also shown in Table 4-1. Adding 5%/2.5% methanol/TBA to 11.0-psi RVP gasoline increases RVP by 2.2 psi. Adding 10 percent ethanol to 11.0-psi RVP gasoline increases RVP by 0.40 psi. Thus, their addition to gasoline must be accompanied by an even greater reduction in butane/pentane content, though the alcohols' high-octane compensates for that of butane in this case.

Table 4-1

Blending Values for Selected Hydrocarbons and Alcohols*

Hydrocarbons	RVP Blending Value (psi)
n-Pentane	15.6
Iso-Pentane	20.4
n-Butane	65
Iso-Butane	92.8

Alcohols

Property	10% Ethanol	2.5% Methanol 2.5% T-butanol	5% Methanol 2.5% T-butanol
Reid Vapor Pressure, psia	15.0	54.0	40.0
Percent Distilled at -			
160°F	220	115	175
210°F	137	110	105
230°F	108	100	100
330°F	100	100	100
Research Octane	133.6	120.7	124.7
Motor Octane	101.8	96.5	97.3
(R+M)/2	117.6	108.6	111.0

---

* The contribution to the finished fuel parameter is determined by multiplying the blending value by the volume percent of the compound in the fuel. The net effect of adding a compound is the volume percent of the compound times the difference between the blending value of the compound and that for the compound being replaced.

III. The Bonner and Moore Study

Bonner and Moore Management Science conducted a study on the refinery cost impact of vapor pressure control under a number of subcontracts with Southwest Research Institute (SwRI) and Jack Faucett Associates (JFA) as contracted by the Environmental Protection Agency. The results of the study are contained in a fully documented final report by Bonner and Moore entitled *Estimated Refinery Cost Impact of Reduced Gasoline Vapor Pressure*.[1] The general methodology and major assumptions of Bonner and Moore's study are presented below in Section III.A. The results of the study are presented in Sections III.B and III.C. The reader is referred to the Bonner and Moore report for more specific details of the refinery cost study. No attempt is made here to explain the B&M study in detail because of its complexity and the availability of the final report, which is an independent document that fully details the study and results.

A draft of this study (dated March 1, 1985) was sent to the American Petroleum Institute (API), the Motor Vehicle Manufacturers Association (MVMA), and the Motor Equipment Manufacturers Association (MEMA) for peer review. A copy of this draft and all comments received are contained in Docket A-85-21 in the West Tower Lobby at EPA Headquarters, 401 "M" Street, S.W., Washington, D.C., 20460, where they can be viewed or copied (for a reasonable fee) during working hours. The comments received from these organizations were addressed to the fullest extent possible in the final report (dated July 10, 1985). However, some of the comments could not be addressed without further modelling and most of the ongoing work described below is intended to address such comments.

A. Bonner & Moore's Refinery and Petrochemical Modeling System

EPA contracted Bonner and Moore to use their proprietary linearly programming (LP) computer model, designated the Refinery and Petrochemical Modelling System (RPMS), to estimate the refinery costs of reducing RVP and $\%_{160}$. One and two-psi RVP reductions below the maximum specified ASTM(D439) RVP and 5 and 10 percent reductions in maximum allowed $\%_{160}$ (from the 35 percent allowed in the base case) were analyzed for each of three geographic gasoline-refinery regions referred to as Petroleum Administration for Defense Districts (PADDS I, II and III). It was assumed that the other two districts, PADDs IV and V (excluding California), could be approximated by the average of PADDs II and III. California gasoline consumption (roughly 11 percent of the national consumption) was excluded since California already restricts gasoline RVP to 9.0 psi.

The national average costs for RVP reduction were estimated by consumption weighting the PADD-specific costs obtained from the RPMS. The costs of controlling the volatility of both alcohol-free gasoline and methanol and ethanol blends were examined. Volatility controls were applied uniformly to all three grades of gasoline; unleaded regular, unleaded premium, and leaded regular. The volume fractions of national gasoline production contributed by each of the grades were 65 percent unleaded regular, 18 percent unleaded premium, and 17 percent leaded regular. Leaded gasoline is allowed to contain only 0.1 gram per leaded gallon of lead, so the effects of EPA's lead phasedown program are fully factored in.

There are also some additional assumptions that had to be made in modelling the alcohol-fuel blends. First, gasoline production was set at the same level used in the alcohol-free cases. No fuel economy changes that might apply to alcohol-containing fuels were taken into account. Furthermore, 100 percent of each grade of gasoline, unleaded premium, unleaded regular and leaded regular, was assumed to contain the specified concentration of alcohol. While this is not realistic, it was the most convenient way to include alcohols in the RPMS and the results appear to be reasonable. (As will be discussed below, this same approach was used to model ethanol blends and the results were clearly unreasonable). Also, a lower RVP case study of 3 psi below the baseline vapor pressure was evaluated for the methanol blend because of the possibility that commingling of the blend with alcohol-free gasoline would increase RVP beyond that of either fuel due to the azeotropic behavior of alcohol and hydrocarbon mixtures (discussed further in Section IV.C. of Chapter 2). The 1-psi further reduction in vapor pressure would tend to partially offset any increase in vapor pressure due to such commingling effects, resulting in evaporative emissions equal to those for alcohol-free fuels.

The estimated costs in all cases for each PADD were developed by the RPMS using a single "super refinery" to represent all of the refining capabilities of that PADD (i.e., the average refinery). This super refinery was required to produce all of the gasoline projected to be produced by all of the individual refineries in that PADD in the timeframe of the study, which was 1990. Individual refineries would be expected to experience costs both above and below that estimated by the RPMS, but on average, the actual costs should be close to that projected by the model. The complexities involved with modeling individual refineries make such an approach economically infeasible and make the use of a single refinery a necessary limitation of this study.

The gasoline costs estimated by the RPMS are, by design, incremental in nature and do not attempt to represent the full cost of refining gasoline. This avoids a number of complex issues associated with valuing capital equipment already in place. As the desired output is the effect of RVP on refining costs, a difference between an uncontrolled and controlled scenario, this is fully satisfactory for this study.

To accomplish this, a base 1990 case is run to determine optimal process requirements and refinery costs associated with producing the 1990 product slate, considering process capacities known to be available in 1984, and, thus, not requiring capital investment. The controlled case is run in an analogous fashion (i.e., a fresh optimization from 1984 capacities), only with a lower RVP or $\%_{160}$ product. Conceptually, this approach assumes that investment occurring between now and 1990 in the uncontrolled case can be redirected toward more productive use, if economically desirable, in the controlled case. This may or may not be the case, depending on the timing of any volatility controls, and is being investigated more fully via further modelling runs.[2] However, information that is available on some of the past model runs shows that very little of the investment occurring in the base case does not also occur in the controlled case.[2] Thus, little redirection of 1984-1990 investment appears to be occurring and the effect of allowing this in the modelling runs appears to be small.

For those readers investigating such details, it should be noted that the RPMS runs tend to project sizable capital investments between 1984 and 1990 for the base cases even though the refinery industry as a whole is expected to invest little for gasoline capacity aside from environmental control (i.e., lead phasedown).[3] This occurs because the current capacity of many peripheral processes (e.g., cooling towers) is not known and was presumed to be zero in 1984 for modelling purposes. Thus, the required 1990 base capacity for these processes is considered to be entirely incremental, though in all likelihood, the vast majority of it is currently in place. These sizable capital investments have no direct effect on the estimated RVP control costs, nor the estimated capital investment required for RVP control, since these are incremental costs involving the subtraction of base case costs from the controlled case costs, both of which contain these costs. It simply means that the capital investment shown for either the base or controlled cases cannot be used to estimate the total capital investment required by the refining industry between 1984 and 1990. However, as the current capacities of some of these peripheral processes may be in excess of that needed in 1990, the model may be overestimating the additional capacity needed for RVP control. The degree to which this may be occurring is unknown and is not easily estimated.

Present RPMS runs also assume that all capital investment is amortized over year-round production. This is appropriate in the base case, since most of this equipment is of the kind that is used year round. However, equipment purchased expressly for RVP control might only be used during the specified RVP control season. As discussed in Chapter 2, ozone violations are prevalent in the summer months, so RVP control might only be required during part of the year. For purposes of this analysis, a 4-month summer control period (i.e., June-September) was chosen. However, a summer period of 3, 5, or 6 months could also have been examined. This RVP control equipment may also be useful during the non-summer period, but to what degree is not known. Additional work is underway to estimate the non-summer benefit.[2] Thus, the current RVP control costs may underestimate the impact of capital investment on a per-gallon basis for a summer-only control strategy.

In the extreme case that the capital investment associated with RVP control has no value outside of the control period (i.e., the effect of capital on the cost of gasoline per gallon was 3 times higher, based on a 4-month summer period) and this caused the model to avoid all incremental capital investment (i.e., opt for operating modifications), the RVP control cost would be no greater than that estimated under a no-investment scenario. This scenario was modelled primarily to simulate the situation where the leadtime granted to refiners prior to RVP controls was insufficient to design and build new capital, but it applies as well to the extreme situation in which the model itself avoids all incremental capital investment because capital investment associated with RVP control has no value outside of the RVP control period. While in theory the cases were to be strictly no new investment, this stipulation had to be relaxed in practice, again due to the unknown current capacities of many peripheral processes. It did not seem reasonable to limit such capacities to those required in the base case, because historic gasoline production has been much higher than projected 1990 levels and much excess capacity could exist. At the same time, the degree of this excess is unknown. Thus, the no-investment costs may be underestimated, since the benefit of some capital investment may be included. The extent to which this is true is not known and is not easily estimated. Thus these costs represent the best estimates available under such conditions.

Another important aspect of modelling refinery RVP control is the treatment of natural gas liquid (primarily butane) supply and demand. Currently the butane market varies dramatically between summer and winter. With gasoline RVP levels 2 psi higher in the winter (corresponding to a butane composition increase of 4 percent by volume), butane supplies tend to be short and prices high. In the summer, the opposite is true. With RVP control, even more butane will be available in the summer and prices could decrease further. This potential price decrease is dependent on the entire butane/petrochemical market and not just on petroleum refinery operations. Thus, a model such as RPMS, which only models petroleum refining, cannot project the price drop. In fact, the price of butane must be input to the model. However, two types of situations were modelled using RPMS to simulate the effect of the potential price drop.

The first situation assumed that butane could be purchased or not purchased at its current price, which varies with PADD, depending on its economic usefulness. This situation is referred to as the "open" NGL purchase scenario. Butane availability was limited to that purchased by refineries in recent times. The second situation forced the refinery to purchase all of the available butane at the current summer price. This situation is referred to as the "fixed" NGL purchase scenario. The first situation was intended to place a lower limit on RVP control costs by allowing refineries to sell any excess butane generated by RVP control at current market prices. In reality, lower butane prices would probably occur, thereby reducing the profitability of doing this and also increasing the cost of RVP control. The second situation was designed to place an upper limit on RVP control costs by requiring the refinery segment of the butane market to use all of the excess butane at current market prices. In reality, prices would drop and other segments at the market would utilize at least part of the butane excess and result in lower RVP control costs.

Practically, there are a number of potential problems even with this bracketing analysis. One, when the RPMS was used to model the first situation, refineries could not actually sell butane generated within the plant at the current market price. They could only avoid purchases. Thus, RVP control costs are not as low as they might have been. Two, butane availability was limited to historical refinery purchases. This is not necessarily consistent with the conclusion of Section IV in Chapter 2, where it was concluded that RVP nationwide could increase by 1990 to ASTM limits. This conclusion implies that butane usage would increase by 1990 without RVP controls. Lead phasedown may actually cause this additional butane to be produced within the refinery. However, if it does not, more butane could be purchased, as butane supplies were exhausted in many of the base scenarios. This would lower the cost of producing gasoline in the uncontrolled cases and, thus, increase the cost of RVP control. The effect of both of these potential problems is now being analyzed via additional modelling runs.[2] In addition, analysis of the impact of RVP control on the entire butane market was performed.[4] Its results are described in Section IV, below, and are being used in the additional modelling runs to more accurately model butane price effects.

Until more detailed information is available from additional RPMS cases currently being evaluated, the midpoint between costs under the "fixed" and "open" NGL purchase scenarios will be used for the cost of RVP control. This decision is subject to change based on new data on the effect of RVP control on butane value, but is the best estimate based on data currently available.

The final aspect of the RPMS deserving discussion here is the way the model simulates ASTM gasoline specifications. RVP levels for the uncontrolled RVP base case were set at maximum ASTM D-439 RVP specifications. PADD average maximum RVPs were estimated by volumetrically weighting the RVPs of all the gasoline produced by refineries in a particular PADD. National average maximum RVPs were estimated by volumetrically weighting the PADD-specific RVPs by the volume of gasoline produced in each PADD. RVP of PADDs 4 and 5 was assumed to be the average of the RVPs for PADDs 2 and 3. The PADD-specific RVPs and national RVPs are presented in Table 4-2. The volumetric production weighting factors are presented in Table 4-3. Current (1984) national average gasoline RVP, as determined from the MVMA fuels survey, is 10.89 psi, which is near the maximum ASTM RVP specification of 11.27 psi. It is assumed that, by 1990, the national average RVP will equal the maximum ASTM RVP specification. This was discussed in detail in Chapter 2, Section IV.

Besides RVP, ASTM addresses fuel volatility by specifying minimum and maximum temperatures at which specified fractions of the fuel are evaporated via distillation (i.e., T_{10} and T_{50}) as discussed in Chapter 2, Section IV. Such specifications do not lend themselves to linear programming since temperatures at which certain fuel volumes are evaporated cannot be easily manipulated when two fuel streams are merged. It is much easier to work in the reverse mode, the percent fuel evaporated at specific temperatures (i.e., $\%_{160}$), since these can be volumetrically averaged when two streams are blended together. This is the mode in which the RPMS works. It is possible to convert from one mode to the other, but only approximately. Thus, at the present time, it is not clear precisely how the RPMS limits (other than RVP) approximate those of ASTM. However, the RPMS requirements specified by B&M for maximum percent of gasoline evaporated at a given temperature appear to be within the ASTM requirements specifying minimum and maximum temperatures corresponding to a given percent of gasoline evaporated. ASTM D-439 requirements

Table 4-2

National and PADD-Specific RVPs and $\%_{160}$s Resulting from Bonner & Moore RPMS Cases

PADD	NGL Purchase Scenario	Level of RVP Control					
		Baseline (B)		B-1 psi		B-2 psi	
		RVP	$\%_{158}$	RVP	$\%_{158}$	RVP	$\%_{158}$
I	Open	11.5	34.978	10.5	33.7	9.5	32.1
I	Fixed	11.5	34.978	10.5*	33.778*	9.5	32.0
II	Open	11.46	33.028	10.46	32.487	9.46	31.808
II	Fixed	11.46	35.0	10.46	33.284	9.46	30.739
III	Open	11.12	33.144	10.12	30.753	9.12	28.325
III	Fixed	11.12	33.144	10.12*	31.184*	9.12	28.28
Nat. Avg	Open	11.27	33.27	10.27	31.59	9.27	29.82
Nat. Avg	Fixed	11.27	33.92	10.27*	32.11*	9.27	29.42

---

* Found by interpolation between (B) and (B-2) cases for the II_F condition
RVP = midpoint between (B) and (B-2)
$\%_{158} = (B) - 0.403\,[(B) - (B-2)]$

Table 4-3

Cost of RVP Control
($ per Barrel of Gasoline)

	PADD				
RVP Reduction, psi	1	2	3	4 + 5 (ex. CA)[1]	Total U. S. (ex. CA)[2]
Alcohol-Free Gasoline					
With Investment, Open Butane Purchases					
1	0.184	0.365	0.211	0.288	0.259
2	0.547	0.748	0.501	0.625	0.587
With Investment, Fixed Butane Purchases					
1	0.189[3]	0.396	0.212[3]	0.304	0.271
2	0.561	0.857	0.504	0.681	0.626
With Investment, Average of Fixed and Open Butane Purchases					
1	0.186	0.380	0.212	0.296	0.265
2	0.554	0.802	0.502	0.653	0.606
No Investment, Fixed Butane Purchases					
1	0.214[4]	0.501[4]	0.300[4]	0.401	0.358
2	0.641	1.084	0.713	0.899	0.826
No Investment, Estimated Average of Fixed and Open Butane Purchase					
1	0.211	0.480	0.300	0.390	0.350[5]
2	0.633[5]	1.014[5]	0.710[5]	0.862[5]	0.800[5]
2.5% MeOH + 2.5% TBA Blend, with Investment, Open Butane Purchases					
1	0.369[6]	0.407[6]	0.314	0.360	0.35
2	0.815	0.898	0.692	0.795	0.77
3	1.370[7]	1.509[7]	1.163	1.336	1.29
5.0% MeOH + 2.5% TBA Blend, with Investment, Open Butane Purchases					
1	0.195[8]	0.387[8]	0.224[8]	0.298	0.27
2	0.581[8]	0.794[8]	0.532	0.676	0.62
PADD-Specific Fraction of Total Gasoline Volume (%)					
	8.83	29.25	53.99	7.93	100.00

Footnotes on following page.

Table 4-3 (cont'd)

---

1 Estimated as average of cost for PADDs 2 and 3.

2 Total U.S. (ex. CA) costs were estimated by volumetrically weighting of PADD-specific costs for PADDs 1, 2, 3, and 4 and 5 (excluding California) using PADD-specific gasoline production.

3 Actual case not run, cost estimated from open butane purchase for 1-psi RVP reduction using the percentage increase for 2-psia reduction costs between open and fixed NGL purchases.

4 Actual case not run, cost estimated from fixed butane purchase costs with investment for 1-psi RVP reduction using the percentage increase between 2-psia reduction costs with and without investment.

5 These costs were estimated from the No-Investment costs for fixed butane purchases presented in the previous row using the ratio of midpoint (open-fixed)/2 vs. fixed butane purchases costs for the cases with investment.

6 Actual case not run, cost estimated by applying ratio of 1-psi reduction cost to 2-psi reduction cost for PADD 3 control to the 2-psi reduction cost for PADD in question.

7 Actual case not run, cost estimated by applying ratio of 3-psi reduction cost to 2-psi reduction cost for PADD 3 control to the 2-psi reduction cost for PADD in question.

8 Actual case not run, cost estimated using the ratio of corresponding costs from open butane purchase cases for alcohol-free gasoline with investment applied to PADD 3 cost for 5%/2.5% MeOH/TBA from B&M.

for minimum and maximum temperatures corresponding to a given percent of gasoline evaporated are not tight specifications, and current fuels are not being restricted by these requirements.

The point of major concern on the gasoline distillation curve is the $\%_{160}$, as discussed in Chapter 2, Section IV. Bonner and Moore limited the maximum $\%_{160}$ to 35 percent for the RPMS cases in their original study. This resulted in the values of $\%_{160}$ presented in Table 4-3, for the specific PADDs and for the volumetric weighted national average. Current (1984) national average gasoline volatility properties are 10.89-psi RVP and 32.6 $\%_{160}$. These values are those for volumetrically weighting all gasoline grades (65 percent unleaded regular, 18 percent unleaded premium, and 17 percent leaded regular), but are also the same as those for unleaded regular gasoline as presented in Table 2-7 of Chapter 2, Section IV. The average $\%_{160}$ of current gasolines is approaching 35 percent, indicating that the B&M restriction of 35 $\%_{160}$ is not too lax. Therefore, the B&M costs for RVP control with $\%_{160}$ restricted to 35 percent appear reasonable from this point of view.

B&M modelled some additional cases to evaluate the cost of further controlling $\%_{160}$, both independently and in addition to RVP control. The cases evaluated and the results of running these cases with the RPMS are presented in Section III.C. of this chapter.

B. Refinery Costs of RVP Control

The projected costs of 1- and 2-psi RVP reductions below the maximum ASTM-specified RVP for various gasoline types and other scenarios are shown in Table 4-3. Before discussing the results of Table 4-3, it should be noted that the $\%_{160}$ of these fuels are indirectly reduced through this RVP control, because removing compounds which contribute to high RVP also lowers $\%_{160}$, to a certain extent. The reductions in $\%_{160}$ associated with these 1- and 2-psi RVP reductions for the "open" NGL purchase scenario are 1.7 percent and 3.5 percent, respectively, as indicated by the national average levels for $\%_{160}$ presented in Table 4-3. $\%_{160}$ is reduced 1.8 and 4.5% for the corresponding "fixed" NGL purchase scenario.

The cost of controlling the RVP of alcohol-free gasoline is of primary concern, since it represents nearly 89 percent of all gasoline sold in the U.S. (with methanol blends making up 4 percent and ethanol blends the other 7 percent of the nations gasoline sales.) As can be seen in Table 4-3, the nationwide-average cost of reducing RVP by 1 psi is 0.62-0.95

cents per gallon ($0.259-0.358 per bbl), while the cost of a 2-psi reduction is greater than two times that, or 1.40-1.97 cents per gallon ($0.587-0.826 per bbl), depending on how capital investment and the butane market are treated.

The least expensive RVP control scenarios are those in which the refineries have the ability to invest in capital equipment to optimize their refinery processes. This situation occurs when the controls are to be in place long enough to justify the capital investment and after refiners have had sufficient time to design and implement new equipment. This definitely applies to the long-term control scenario (i.e., 2010) and may apply to short-term controls if the above two conditions are met.

In addition, two extreme scenarios were evaluated with capital investment permitted, one with "open" NGL purchases and one with "fixed" NGL purchases, as described earlier. RVP control for the "open" NGL purchase scenario was slightly less expensive than for the "fixed" case ($0.587 vs. 0.626 $/bbl for a 2-psi RVP reduction, respectively). As also described earlier, the current best estimate of the RVP control cost is halfway between these two values.

For the no investment situation, only fixed NGL cases were modelled. Open NGL costs were estimated from the runs "with investment" to determine the best estimate midpoint "no-investment" cost, as shown in Table 4-3. These "no investment" costs may be appropriate under short-term control if refineries are not given sufficient time to invest in capital prior to control or if the period of control is too short to justify capital investment (generally thought to be 2-4 years).

Thus, the "with investment" costs are used to represent long-term control costs and both "with" and "without investment" costs are used to represent the range of potential short-term control costs. These costs are used in determining the overall costs of RVP control presented at the end of this chapter and also the cost-effectiveness of RVP control ($/ton) presented in Chapter 6.

The cost of controlling the RVP of alcohol-blends follows the same general PADD-to-PADD trend as that for alcohol-free gasoline. Overall, the cost of vapor pressure control is greater for gasoline containing the 2.5/2.5 percent methanol/TBA blend, than for alcohol-free gasoline. The cost of a 3-psi reduction for PADD 3 (the only PADD evaluated) is increased 68 percent over that of just a 2-psi reduction. This increase may differ slightly between PADDs, but was assumed in Table 4-2 to be relatively constant.

The cost of reducing RVP for the 5.0/2.5 percent methanol/TBA blend, in contrast, is less than that for the 2.5/2.5 percent methanol/TBA blend and is 6-7 percent greater than that for alcohol-free gasoline, on average. Bonner and Moore credits the smaller cost to the non-linear vapor pressure blending behavior of the additional methanol, as indicated by the blending values shown in Table 4-1. The additional 2.5 percent of methanol incurs a small additional vapor pressure penalty but contributes a larger octane benefit. As this is expected to be more popular than the 2.5/2.5 percent methanol/TBA blend in the future, and its RVP control costs are so close to that for alcohol-free gasoline, only the cost for alcohol-free gasoline will be used hereafter.

As indicated above, attempts were made to model 10 percent ethanol blends, in the same manner as methanol blends. However, in all cases, the base (uncontrolled) RVP was already very near or below the 2-psi reduction level. This was an artificial result of restricting $\%_{160}$ to 35 percent. This is unrealistic for current ethanol blends, as ethanol dramatically affects $\%_{160}$ and current levels of $\%_{160}$ for ethanol blends at 11.5-psi RVP are around 42 percent. Thus, the forced lowering of $\%_{160}$ likely forced most of the butane out of the fuel and lowered RVP dramatically prior to control. This situation is being corrected in additional modelling currently being conducted by B&M. Results are not available yet, but will be incorporated in the study of controlling evaporative emissions as soon as the RPMS case studies are complete.

Thus, little can presently be said quantitatively about the cost of controlling the RVP of ethanol blends. Qualitatively, ethanol has a smaller RVP effect and greater octane effect than methanol/TBA mixture (see Table 4-1). Thus, one would expect its presence to impact RVP control costs less than the methanol/TBA mixture when $\%_{160}$ is not controlled. This is being further investigated via further RPMS modelling runs.[2] The economic impact on the ethanol blending industry of controlling the quality of the finished blend (i.e., eliminating splash blending and requiring coordinated blending) is also being investigated.[5] This is discussed further in Section III.D.

C. Refinery Cost of Controlling the Percent of Gasoline Evaporated at 160°F

The significance of controlling $\%_{160}$ has already been discussed in detail in Chapter 2, Section IV. In review, the representative volatility measure with respect to the portion of hot-soak emissions occurring from the fuel metering system appears to be $\%_{160}$, because 160°F is a typical maximum carburetor bowl temperature during a hot-soak. B&M was instructed to evaluate the cost of controlling $\%_{160}$ through running additional RPMS cases with restrictions on $\%_{160}$, as it may be valuable to control $\%_{160}$ in addition to controlling RVP. This section discusses the RPMS cases evaluated by B&M and the sensitivity of refinery costs to controlling $\%_{160}$.[1]

Two sets of cases have been run to date to evaluate the effect of controlling $\%_{160}$ on refinery costs. They were run for PADD 2 under the fixed NGL purchase scenario. This situation was believed to result in the worst-case cost for $\%_{160}$ control since it showed the highest RVP control cost and the greatest sensitivity to fixing NGL purchases. The first set of cases was conducted for alcohol-free gasoline, while the second was run for 5/2.5 percent methanol/TBA blends. A third set of cases is currently being run using the RPMS to evaluate refinery cost of controlling $\%_{160}$ at different RVPs for PADD 3, because 54 percent of national gasoline production occurs in PADD 3 and these results will represent more of a national average than those for PADD 2.[2] The results of running the third set of cases are not available at this time, but will be incorporated into the analysis as they become available.

The results for the first two sets of cases are detailed in B&M's supplement to their earlier report.[1] They are summarized in the following paragraphs.

1. Alcohol-Free Gasoline

Results of evaluating the first set of cases run to determine the refinery cost of controlling $\%_{160}$ of alcohol-free gasoline indicate that RVP control cost decreases as $\%_{160}$ restrictions for the baseline uncontrolled RVP scenario and for controlled RVP scenarios are limited below 35 percent. Results of running 6 cases were used to evaluate refinery control costs at different RVP and $\%_{160}$ restrictions. These 6 cases run for PADD 2 are described in Table 4-4. The resulting costs and actual RVPs and $\%_{160}$s are presented in Table 4-5.

It is difficult to separate the costs of controlling RVP and $\%_{160}$, because refinery operations necessary for RVP control, as discussed in Section II, may also result in controlling $\%_{160}$. The $0.857 per barrel cost for a 2-psi RVP reduction for PADD 2 under the fixed NGL purchase scenario also includes (unavoidably) a 4.26 percent decrease in $\%_{160}$. This is because controlling gasoline RVP involves removing butane, which affects $\%_{160}$. A 2-psi reduction in RVP may be accomplished by an estimated 4 percent reduction in butane content, which, absent other changes, also reduces $\%_{160}$ 4 percent because of butane's low boiling point.

Table 4-4

RVP and $\%_{160}$ Restrictions for RPMS Cases Evaluated to Determine Refinery Costs of Gasoline Volatility Control

	Max. RVP = 11.46 psi	Max. RVP = 9.46 psi
Max $\%_{160}$ = 35%	X	X
Max $\%_{160}$ = 30%	X	X
Max $\%_{160}$ = 25%	X	X

X Indicates that RPMS case was run for specified maximum RVP and $\%_{160}$.

Table 4-5

PADD 2 Refinery Costs and Actual RVPs and $\%_{160}$s for RPMS Cases Described in Table 5-4.

All gasoline grades are alcohol-free.

1. RVP = 11.46 Cost = 2. RVP = 9.46
$\%_{160} = 35\%$ \$.857/bbl $\%_{160} = 30.74$

Cost = \$0.485/bbl Cost = \$0.045/bbl

3. RVP = 10.53 Cost = 4. RVP = 9.46
$\%_{160} = 30\%$ \$.417/bbl $\%_{160} = 30\%$

Cost = \$.841/bbl Cost = \$.500/bbl

5. RVP = 9.86 Cost = 6. RVP = 9.11
$\%_{160} = 25\%$ \$.075/bbl $\%_{160} = 25\%$

Controlling RVP 2 psi below the ASTM maximum for PADD 2 with $\%_{160}$ restricted to 30 percent, is less costly than at 35 percent, partially because the 30 percent restriction for the uncontrolled RVP scenario limits RVP to 10.53 psi. This is nearly 1 psi below the 11.46-psi maximum ASTM specified RVP level. Therefore this $0.417/bbl cost of controlling RVP to 9.46 psi does not assess the cost of controlling RVP 2 psi, but rather only assesses the cost of controlling RVP 1.07 psi. Likewise the cost of controlling RVP to 2 psi below the ASTM maximum specified RVP level with $\%_{160}$ restricted to 25 percent is only $.075/bbl, because there is actually only a 0.75-psi reduction in RVP due to the 25 percent $\%_{160}$ restriction.

The costs illustrated in the matrix of Table 4-5 also indicate the cost for controlling $\%_{160}$ at constant RVP. The costs are $0.45/bbl for $\%_{160}$ between 30.74 and 30.0 percent and $0.50/bbl for $\%_{160}$ between 30 and 25 percent, both at 9.46-psi RVP. Other costs included in the matrix are costs for controlling both RVP and $\%_{160}$ simultaneously.

It is clear from this matrix that the refinery cost of gasoline volatility control is a function of the level of control of both RVP and $\%_{160}$. The costs presented for RVP reduction in the previous section (at $\%_{160}$ restricted to 35 percent) are the most representative RVP control costs, but may be reduced by as much as a factor of 2 if baseline $\%_{160}$ levels were lower. MVMA survey data for fuels sampled during July of 1984 indicates that the average $\%_{158}$ (which can be used to approximate $\%_{160}$) for volatility Class C gasolines was 32.6 percent (discussed in Chapter 2, Section IV). Assuming no change in future $\%_{160}$ levels (there is currently an upward trend), the RVP control cost in PADD 2 may currently be overestimated slightly since its $\%_{160}$ is being reduced from a greater value, 35 percent, to 30.74 percent. The sensitivity of overall costs and cost-effectiveness of gasoline volatility control to restricting the $\%_{160}$ are addressed further in Chapter 6, Section III.

2. Methanol/TBA Blends

The second set of cases evaluated by B&M using their proprietary RPMS were run to study the refinery cost of controlling $\%_{160}$ for gasoline containing 5/2.5 percent MeOH/TBA. These cases are the same as those run for the alcohol-free study on refinery cost of controlling $\%_{160}$, as illustrated in Table 4-4. The results of running these cases are presented in Table 4-6. They may be analyzed as were those of the alcohol-free $\%_{160}$ control study. These results are summarized below.

Table 4-6

PADD 2 Refinery Costs and Actual RVPs and $\%_{160}$s for RPMS Cases Described in Table 5-4

All gasoline grades contain 5/2.5% MeOH/TBA.

1. RVP = 11.20 $\%_{160}$ = 35%	Cost = $0.491/bbl	2. RVP = 9.46 $\%_{160}$ = 35%
Cost = $1.039/bbl		Cost = $0.620/bbl
3. RVP = 9.89 $\%_{160}$ = 30%	Cost = $.072/bbl	4. RVP = 9.46 $\%_{160}$ = 30%
Cost = $1.296/bbl		Cost = $1.224/bbl
5. RVP = 8.10 $\%_{160}$ = 25%	Cost = $.000/bbl	6. RVP = 8.10 $\%_{160}$ = 25%

Cost of RVP control to 9.46 psi (2 psi below the maximum ASTM specified RVP of 11.46 psi) is lower for low $\%_{160}$ restrictions than for high $\%_{160}$ restrictions. This is because actual RVP reduction is less as $\%_{160}$ restriction is lowered. The cost differences are $0.491/bbl for RVPs from 11.2 to 9.46 psi (a 1.74-psi RVP reduction) at a 35 percent $\%_{160}$ restriction, and no cost at a 25 percent $\%_{160}$ restriction because this $\%_{160}$ restriction limits RVP to 8.10 psi for even the uncontrolled RVP case, which is already less than 9.46 psi. The cost of a 5 percent difference in $\%_{160}$ may be estimated from the cost of reducing $\%_{160}$ from 35 to 30 percent at RVP equal to 9.46 psi. This cost is $0.620/bbl.

The $0.491/bbl cost for RVP control in PADD 2 to 9.46 psi at $\%_{160}$ restricted to 35 percent is probably a slight underestimation of the cost of reducing $\%_{160}$ RVP of methanol/TBA blends 2 psi, because RVP is only reduced 1.74 psi at constant $\%_{160}$. The $\%_{160}$ of methanol blends is, as discussed in Chapter 2, Section IV.C., higher than that of alcohol-free gasoline and likely exceeds 35 percent, on average.

IV. Effect of RVP Control on the Butane Market

The major method of RVP control is to remove butane from gasoline, as described in Section II, and to replace the butane with heavier components. The butane that is no longer used in gasoline is made available to the market and this excess supply could and likely will decrease the market price of butane and economically impact suppliers and purchases. While in aggregate, this economic impact should be zero (i.e., the benefits to purchasers of cheaper butane should equal the cost to suppliers), there may be economic impacts on isolated segments of the butane market. Thus, Jack Faucett Associates (JFA) was contracted to evaluate the effect of reducing the RVP of gasoline on butane prices and usage. The results of their study are presented in a report entitled, "The Butane Industry: An Overview and Analysis of the Effects of Gasoline Volatility Control on Prices and Demand".[4] The results of this study are summarized below.

JFA concluded that excess butane supply from any level of RVP reduction evaluated would be large compared to actual butane demand as a fuel or a feedstock priced at $23.08/bbl, the baseline annual average national price of butane. Because of the limited demand for butane as a unique fuel or petrochemical feedstock, a small level of RVP reduction results in enough excess butane to cause butane prices to fall to the level of the petrochemical floor price, estimated to be $20.26 per barrel in 1990. Here butane is used in place of other feedstocks primarily in the production of acetic acid and ethylene. The demand for these other feedstocks is large enough that even extreme reduction of RVP would not result in providing enough additional butane to drive the price below the petrochemical floor price. JFA estimates that, at any price above the $20.26/bbl petrochemical floor price, no more than 850,000 bbls of butane per year could be absorbed by the fuel and petrochemical feedstock sectors of the butane market. This volume is significantly less than the 8.6 million barrels of excess butane estimated to result from a 1-psi RVP reduction for a 4-month control period. On the other hand, the 42.9 million barrels of excess butane estimated to result from a 2-psi reduction in gasoline RVP over a 6 month control period would all be used at the petrochemical floor price at $20.26/bbl.

These prices for butane estimated by JFA are similar in magnitude to those presented in the B&M study.[1] The raw material costs for both normal and iso-butane for PADD 3 were estimated at $23.30/bbl in the B&M study. The PADD 3 prices are the best choice for comparison with JFA's national average price because PADD 3 produces over 50 percent of the nations gasoline. Under the "open" NGL situation, these prices were assumed to remain constant and refineries could avoid purchasing butane, if desired. However, they could not sell butane produced within the refinery. Under the "fixed" NGL situation, refineries were forced to purchase all the NGLs projected to be available at these same prices, regardless of its value to the refinery. It is very useful to compare the incremental refinery values for butane under these two conditions with the petrochemical floor price of $20.26/bbl determined by JFA.

The incremental refining values of butanes for all scenarios, as estimated by B&M, are presented in Table 4-7. Incremental refining values (value to refinery of the last barrel used) of normal butanes under the "fixed" NGL purchase scenario are $21.04/bbl, $16.44/bbl, and $21.30/bbl for a 2-psi RVP reduction for PADDs 1, 2, and 3 respectively. The incremental values of iso-butane are much higher; $27.05, $21.69, and $26.86 per barrel for PADDs 1-3, respectively. Where these figures are below the $23.30/bbl price of butane, this means that butane prices would have to drop to these levels for refineries to purchase and utilize all of the NGLs projected to be available.

As can be seen, the incremental values for iso-butane are all above the floor price of $20.26/bbl floor price estimated by JFA. As the sales-weighted value is well above $23.00/bbl, iso-butane prices should not drop and no excess should reach the market.

Table 4-7

Incremental Refining Values of Butanes ($/bbl)

	PADD-1		PADD-2		PADD-3	
	Open	Fixed**	Open	Fixed**	Open	Fixed**
RVP: Base						
Normal Butane	35.27*	35.24	24.77*	20.98	29.80*	29.80
Iso-Butane	32.03*	32.05	24.75*	23.30	31.16*	31.16
RVP: -1-psi						
Normal Butane	28.75*	na***	23.20	18.37	26.22*	na
Iso-Butane	30.51	na	25.83*	23.46	31.14*	na
RVP: -2-psi						
Normal Butane	21.97	21.04	22.39	16.44	23.30	21.30
Iso-Butane	28.15	27.05	24.89*	21.69	29.04*	26.86

---

* Butane purchases limited by maximum availability.

** Butane purchases required to equal maximum available.

*** na = Case not modelled by Bonner and Moore.

The situation for n-butane is slightly different. The sales-weighted value in the three PADDs is very near the JFA estimated floor price of $20.26/bbl. Thus, the market price of n-butane would likely drop to this level with a 2-psi RVP reduction. However, little n-butane may actually switch to petrochemicals since refineries can apparently utilize all of the excess at this price. Of course, even less effects would be seen with a 1-psi RVP reduction.

In the "open" NGL situation, the incremental butane values are nearly always above the current market price of $23.30/bbl and purchases are often limited by projected availability. This has raised some concerns that the model may be valuing butane-utilizing processes too highly, since such high incremental values would argue for equally high market prices. To further investigate this possibility, Bonner and Moore is evaluating the sensitivity of its model to a number of factors, including base alkylation capacity (a butane consumer) and 1990 butane availability.[5] These results will be incorporated into the study as soon as they are available.

V. Fuel Economy Credit

This section presents an analysis of the effect of reducing the volatility of gasoline on fuel economy. It is hypothesized that, if gasoline volatility is reduced by removing butane from gasoline and replacing it with other fuel components, the energy density of the gasoline will increase. Furthermore, vehicular fuel economy should increase with an increase in fuel energy density. Thus, there should be a fuel economy benefit resulting from reducing the volatility of in-use gasoline. As a result of the analysis, it is estimated that reducing RVP by 1 and 2 psi will increase fuel economy by 0.25 and 0.56 percent for feedback and non-feedback-equipped vehicles.

The remainder of this section explains how these estimated increases in fuel economy were determined. It is divided into three parts: 1) the relationship between gasoline volatility and energy density, 2) the relationship between energy density and fuel economy, and 3) the overall relationship between gasoline volatility and fuel economy.

A. Volatility and Energy Density

Quantifying the relationship between RVP and energy density is difficult because of 1) the complex refinery operations involved in lowering RVP and maintaining octane and other requirements and 2) the relatively wide range of commercial fuel energy contents occurring at any given RVP.

Relevant information from two different sources was available to derive independent estimates of the effect of RVP on energy density. Also, both API and MVMA were requested to submit any relevant information they might have. The two independent analyses and the two submittals are described in the following paragraphs. Table 4-8 details the quantitative results from each for direct comparison.

The first independent analysis used the output of Bonner and Moore's linear programming model, which is being used to estimate the cost of controlling RVP.[1] In addition to RVP and octane, the model generates estimates of other fuel properties, including API gravity, aromatic content, and 50-percent distillation temperature, which can then be used to estimate fuel energy density using a well-accepted relationship defined in ASTM D3338-74. There was significant variation from region to region in the effect of RVP reduction on energy density, resulting from the varying regional composition of gasoline at different RVPs. Energy densities increased 0.22-0.30 percent for a 1-psi RVP reduction and 0.33-0.69 percent for a 2-psi RVP reduction. Weighting the regional effects by gasoline production volume resulted in weighted energy-density increases of 0.25 percent and 0.56 percent for a 1- and 2-psi RVP reduction, respectively.

The second independent analysis examined MVMA fuel survey data from January and July gasoline samples taken from 1979-83 (these were available on tape and could be accessed en masse). The energy content of each fuel sample in the surveys was again estimated from the properties of the fuels using the relationship from ASTM D3338-74, as described above. A linear regression was then applied to relate the RVPs and energy densities (BTUs/gallon) for the nearly 2,000 summer fuel samples and also for the 4,400 summer and winter fuel samples. For the summer gasolines, a 1-psi reduction in RVP from 11.5 to 10.5 psi resulted in a 0.25 percent increase in energy density, with a range of 0.22 to 0.28 percent at 90 percent confidence. For summer and winter fuels combined, a 1-psi reduction in RVP from 11.5 to 10.5 psi resulted in a 0.33 percent increase in energy density, with a range of 0.32 to 0.34 percent at 90 percent confidence. The R^2 was only 0.09 for summer fuels and 0.30 for summer and winter fuels combined, but due to the large number of samples, the relationship is quite certain, as evidenced by the tight 90-percent confidence limits. The regression of summer fuels is probably the most appropriate for use here. The winter fuels were included to provide a wider range of RVPs and to test the sensitivity of the results to range of RVP.

Table 4-8

Effect of Change in RVP on Change In Energy Density

Source of Information	Percent of Increase in Heat Of Combustion (Btu/gal) RVP 1-psi	 RVP 2-psi
1. Bonner & Moore		
PADD 1	.30	.54
PADD 2	.22	.33
PADD 3	.26	.69
Volumetric Wtd. Average	.25	.56
2. MVMA Fuel Sampling Data		
Summer Fuels	0.25	0.50
Summer & Winter Fuels	0.33	0.66
3. MVMA Submittal		
Calculated Effect	0.32	0.64
4. API Submittal	No calculated results	

The MVMA submittal in this area outlined a first-order analysis of the effect of reduced RVP on fuel energy density.[6] They stated that they were not aware of any test data that would provide a direct relationship between RVP reduction through butane control and vehicle fuel economy; however, they did make some calculations to estimate the effect of butane content on energy density. They too used the the method described in ASTM D3338-74 to estimate gasoline energy content from predicted average properties of the gasoline. They estimated the percent decrease in fuel butane content associated with a 1- and 2-psi change in RVP to be 1.8 and 3.7 percent, respectively. Then, assuming that the composition of the non-butane portion of the fuel would remain constant, they estimated the change in the energy density using the relative energy densities of gasoline, and while MVMA did this using three baseline gasolines of various RVP, their analysis ignores the fact that reduced butane content will reduce octane. This octane can be replaced by further processing of the gasoline feed stocks, which will likely reduce energy density, or by increasing aromatic content, which will likely increase energy density. MVMA estimated that 1-psi and 2-psi reductions would increase energy density by 0.32 and 0.64 percent, respectively. As these figures are somewhat larger than those estimated using the Bonner and Moore model and the regression of summer fuel RVPs, it appears that increased processing to replace lost butane dominates somewhat and reduces the net energy increase by about 0.07 percent per psi RVP.

API, in their submittal, stated that there is no predictable relationship between gasoline vapor pressure and gasoline density.[7] They state that a number of compositional changes occur in reducing RVP to ensure that the other properties of the gasoline remain in accord with ASTM specifications and that production volume is maintained. As evidence, they cite the fact that the scatter in the energy densities of surveyed fuels at a specified RVP is greater than the difference in energy density between RVPs, and make the determination that any relationship between RVP and energy density impossible to ascertain. Therefore, they did not submit any conclusions on the net effect of all the factors affecting energy density accompanying a reduction in RVP, other than to state that the relationship is unpredictable.

As our own assessment of the energy densities of MVMA-surveyed fuels indicated, there is a wide variation in energy density at any given RVP and this variation is larger than the effect of RVP. However, the 90 percent confidence limits on the predicted slope take this variation into account and still predict a range of only 0.25±0.03 percent per psi for summer fuel. Thus, while other factors can overwhelm the RVP effect for any given fuel, on average the RVP effect is quite certain and quantifiable. The fact that the Bonner and Moore estimates fall within this small range, and yet were quite independent, is further support for their accuracy.

Given that the analysis of the survey data and the B&M study yield essentially the same results, the B&M estimates will be used here as it is a forward looking study of lower RVP fuels across the board rather than backward looking survey results. The result is that energy density is projected to increase 0.25 percent with a 1-psi reduction in RVP and 0.56 percent with a 2-psi reduction.

B. Energy Density and Fuel Economy

Much data on the fuel economy of all types of vehicles exist in the literature. However, few studies relate fuel economy to fuel energy density. Thus, while the effect of energy density on fuel economy should be more consistent and discernible than the effect of RVP on energy density (once measurement variation is eliminated), few data exist from which to determine accurate estimates. Compounding this is the fact that the random variation in fuel economy measurements is large (e.g., 3-5 percent) relative to the expected change in fuel economy (less than one percent). Three sources of information were used in analyzing this relationship: 1) test data supplied by General Motors and Ford with respect to the CAFE adjustment rulemaking* (use of this information was also recommended by MVMA in their submittal in this area), 2) fuel economy data from EPA's in-house emission factors testing program, and 3) a discussion submitted by API reviewing different factors that affect fuel economy. A theoretical analysis of the vehicle design optimization and performance on the different gasoline types was then used to arrive at a conclusion. These are discussed in order below.

In a letter dated August 15, 1984, General Motors cited data on the relationship between gasoline energy density and fuel economy which was presented in a Chevron Research Co. SAE paper in 1974, and added that GM testing on more recent systems supported the results presented in the SAE paper.[8,9] The vehicles tested by Chevron were from the 1970 and 1972 model years, and the SAE paper points out that these tests can only give an indication of 1970 and 1972 car performance in general. Their results were based on testing six vehicles with six fuels, repeating each vehicle/fuel-specific test at least eight times. Fuel economy was measured by weighing the fuel consumed and measuring the distance travelled during each test cycle. Heat (energy) content of the fuels was calculated using a widely accepted correlation involving API gravity, percent aromatics, and volatility of the gasoline from ASTM-3338. The average value of the ratio of the percent change in vehicular fuel economy to the percent change in gasoline energy density (defined as R) was 0.57. The GM submittal did not supply or refer to any data supporting their average value for R resulting from testing on more recent systems, but they did state that the testing yielded R values ranging from 0.1 to 0.9 with an average of 0.5. In their submittal they suggested an overall average R of 0.6.

---

* See 49 FR 48024, December 7, 1984.

This value of 0.6 for R was later recommended by GM, Ford, and MVMA in response to questions asked by EPA's Certification Division in the EPA memorandum referenced in the supplemental NPRM on the CAFE adjustment rulemaking referenced earlier.[10,11,12] This ratio of increased fuel economy to increased energy content of 0.6 was recommended for all vehicles (without differentiating between feedback and non-feedback equipped vehicles). This ratio is not heavily supported by a large data base, but likewise is not refuted by the data sets used by GM and Ford. The major conclusions of these manufacturers as stated in their January 22, 1985 letters to EPA are discussed below.

In their letter to EPA, GM summarizes data from five vehicles (two with throttle-body injection (TBI) and three carbureted) of model years 1981 and 1984, which are presented in Table 4-9.[10] They include R factors for FTP and highway tests. The method which General Motors used to measure or calculate the fuel economizes of these five vehicles was not stated in the GM letter. The results for FTP testing were an average R of 0.62 for five vehicles, with a range of 0.34-0.89. For the highway test procedure the average ratio was 0.53, with a range of 0.41-0.72. The 0.89 and 0.72 R values were both for a 1984 Pontiac J2000 with TBI.

GM did not explain why R is greater for the FTP tests than for the highway tests. This is not the expected result for two reasons. One, there is more stopping and starting on the FTP than on the highway test (e.g., more accelerations where a carburetor could be operating rich and not able to utilize the extra energy). Two, the FTP contains cold operation, where the highway test does not. Again, the engine will likely be operating rich and the feedback loop will be inoperative during this time. This anomaly in the data is unexplained.

Table 4-9

GM Data on Ratio of Percent Change in Fuel Economy to Percent Change in Energy Density[10]

	R Factor	
Test Vehicle	FTP	HWY
Carbureted Vehicles		
1984 Olds Delta (5.0L, 4bbl.)	0.35	0.51
1981 Olds Cutlass (4.3L, 2bbl.)	0.39	0.41
1981 Chevette (1.6L, 2bbl.)	0.80	0.62
Average	0.51	0.51
TBI Vehicles		
1984 Chevrolet Citation (2.5L, TBI)	0.65	0.41
1984 Pontiac J2000 (1.8L TBI)	0.89	0.72
Average	0.77	0.56
Composite Average (Carbureted and TBI)	0.62	0.53

If the data from the five vehicles are divided into two groups, as illustrated in Table 4-9, the TBI-equipped vehicles show higher R values (0.77 vs. 0.51 for the FTP and 0.56 vs. 0.51 for the highway test) than the carbureted vehicles. The composite data have an average R of 0.58, which may be rounded off to 0.6. However, the fact that the TBI vehicles show higher R values than the carbureted vehicles and the statement that R can approach 1.0 for some operating conditions (i.e., steady state) indicate that it may be appropriate to assume an R higher than 0.6 for fuel-injected vehicles.

Both the TBI vehicles and the carbureted vehicles were probably equipped with electronic feedback control (EFC) operating over most of the test cycle, as all GM vehicles of model years 1981 and later used EFC. Therefore, one can still distinguish between TBI and carbureted vehicles here, but the results (i.e., R values) should be the same for both sets of vehicles, since the real technological difference is between feedback and non-feedback equipped vehicles.

In a direct response to EPA's question, "Is it appropriate and/or possible to account for the effect of fuel energy content on the vehicle's energy efficiency? If so, how should this be done?" GM supplied no other data than that in Table 4-9 and a reference to SAE paper no. 740522 and recommended an R of 0.6.

Ford also recommends that an R = 0.6 be adopted to represent the 1980-85 model year vehicles.[11] The Ford letter of 1/22/85 goes on to state that future model year vehicles could respond differently and, thus, should be evaluated separately if warranted by future fuel specification changes. Ford based their conclusion on repeated test results from four different vehicles with different engines and control systems using two different fuels. Twelve CVS-H and twelve HWFET tests were conducted on each vehicle and with each fuel for a total of 192 tests. The method used to determine the fuel economies of these vehicles (volumetric measurement or carbon balance calculation) was not stated in the Ford letter. These results are presented in Table 4-10.

One of these four vehicles was equipped with electronic fuel injection (EFI), always accompanied by electronic feedback control, while the rest were designated NFB for non-feedback vehicles. The R value for the EFI vehicle for the hot-start test was 0.75. For the hot-start portion of the urban driving cycle (CVS-H) fuel evaluation and the highway fuel economy test (HWFET) fuel evaluation analyses, the R values were 0.71 and 0.84, respectively. The other three vehicles were non-feedback controlled vehicles (NFB) with average R values of 0.35 for the

Table 4-10

Ford Data on Ratio of Percent Change in Fuel Economy to Percent Change in Energy Density[11]

Test Vehicle	M-H HS*	CVS-H*	HWFET*	CVS-C/H*
w/o Feedback Controls				
3.8-216 NFB	0.5974	0.2168	1.1837	
1.6-602 NFB	0.6178	0.5574	0.7173	
5.0-807 NFB	0.2095	0.2687	0.1161	0.846
Average	0.4749	0.3476	0.6724	0.846
W/Feedback Controls				
1.6-343 EFI	0.7502	0.7082	0.8403	1.065
Composite Average (Feedback and Non-Feedback)	0.5437	0.4378	0.7143	0.955

---

* M-H Hot-Start = city and HWFET combined to yield a metro/highway value.
CVS-H = city test cycle - hot-start.
HWFET = highway test cycle.
CVS-CH = City cycle test - cold-start.

CVS-H analysis, and 0.67 for the HWFET fuel evaluation analysis. These R values are significantly lower than those resulting from testing the EFI vehicle. MOBILE3 projections predict that by 1990 nearly 90 percent of gasoline-fueled vehicles in-use will have EFI or will be feedback-equipped carbureted vehicles. Thus, based on the Ford data, it is reasonable to assume an R value higher than 0.6 for vehicles in use in 1990, the majority of which will use EFI.

It should also be noted that this Ford data supports the theory presented earlier; that vehicles tested on fuels of different energy content would provide higher R values over the HWFET than over the CVS-H test cycle. It also contradicts the results of the GM analysis, in which R from the FTP was greater than R from the HWFET. This contradiction indicates the variability in measuring R over different test cycles, and lends some doubt to the accuracy of this method of analyzing R.

Ford states in the January 22, 1985 letter that, though fuel economy should increase due to an increase in the energy content of the fuel the vehicle is operated on, the vehicle cannot utilize 100 percent of the increased energy content of the fuel because there are penalties that are associated with greater fuel density.[11] These penalties are: 1) air/fuel ratio shifts slightly richer, 2) cylinder to cylinder A/F distribution becomes worse, and 3) A/F ratio excursions on transients increase. Ford states that these variations in air-fuel ratio due to changes in fuel properties will prevent the R value from ever reaching 1.0, and thus they recommend R = 0.6. Again, no differentiation was made between R values for carbureted and fuel-injected feedback and non-feedback equipped vehicles, even though the data supports a higher R value for EFI vehicles than for NFB vehicles.

The MVMA letter of January 22, 1985 analyzes the data submitted by GM and Ford and reaches the same conclusion; 0.6 is a reasonable value for R.[12] The MVMA letter does not propose a higher R value for feedback equipped vehicles vs. non-feedback equipped vehicles.

The second source of information was EPA's in-house emission factors testing program. No major conclusions on the relationship between lower RVP fuel and vehicular fuel economy can be drawn from these data due to the large degree of variability in the R values calculated from the EPA test data for vehicles operating on different fuels (R = -4 to R = +5). It appears that the variability associated with the measurement of both fuel properties and fuel economy is larger than the actual changes in energy density (only -0.4 to +1.0 percent). Because of this, the results from this test program could not be used to evaluate R.

Finally, API, in their submittal, stated that there are many variables that can combine with fuel volatility parameters to affect energy density and fuel economy.[3] However, although they mention data reported in CRC Report No. 527 showing the effect of ethanol blends on fuel economy, they did not submit any data relating energy density and fuel economy for alcohol-free gasoline. Since ethanol lowers energy content, rather than raising it as does lower RVP, this severely limits the value of their submittal here.

General Motors also submitted a theoretical argument defending an R valve significantly less than 1.0, in the form of a letter from Chemical Engineering Professor John Longwell of MIT. GM submitted the data from references [4] and [6] to Professor John Longwell of MIT for his analysis and comments. Professor Longwell concluded that the GM suggested value of R = 0.6 is reasonable.[13] Professor Longwell's conclusion was not based on any data other than that already discussed; but he did perform a theoretical analysis of the effects of different gasoline properties (including energy density) on fuel economy. He explains that high density, low H/C fuels may run at higher equivalence ratios resulting in lower efficiency and lower R. This effect is greater for volumetrically metered fuels than for fuel metering controlled by an oxygen sensor. This implies that volumetrically metered fuel systems (i.e., open-loop carbureted vehicles) may yield lower R values than fuel metering controlled by an oxygen sensor, referring to feedback equipped fuel systems.

Longwell goes on to discuss the effect of increasing aromatic content, which increases fuel viscosity, surface tension, and latent heat of vaporization. He writes that these changes decrease evaporation ratio which decreases fuel mixture homogeneity and quality of cylinder to cylinder distribution, both of which lower the fraction of the volumetric heating value that is captured in miles per gallon. Longwell also explains that higher aromatic content also increases flame temperature, which increases heat losses to the cylinder walls, thus, decreasing efficiency, and R.

Longwell concludes that the major changes in the fuel system have not improved the engine's ability to capture the high heating value of higher density fuels. Because he was unable to identify factors that would tend to appreciably increase R above 1.0, he concluded that a multiplicity of effects caused by increased density and aromatic content combine to reduce R. Longwell states that the GM suggested value of R = 0.6 is reasonable, but he does not suggest using different R values for vehicles with different fuel systems.

Because of the inconsistencies in the R values provided by GM and Ford that were discussed previously, and also those in the R values resulting from EPA's in-house emission factors test program, a theoretical analysis of R is necessary. Two arguments may be presented to support an R value greater than 0.6. The first argument addresses the implications of an R value significantly less than 1. The second evaluates the vehicle design optimization procedure and its effect on vehicle operation on different fuels. These arguments are discussed below.

An R of 0.6, as estimated by MVMA, GM, and Ford, indicates that 40 percent of the excess energy available in lower RVP fuels will not contribute to an increase in vehicular fuel economy. Possible sources of the energy losses have been proposed by Ford, GM, and Professor Longwell of MIT. These losses resulting from lower RVP gasoline include increased heat losses to cylinder walls, decreased thermogravimetric efficiency, lower efficiency due to higher equivalence operating conditions, and higher fuel surface tension and viscosity (creating pumping losses).

Ford's explanations for less complete fuel utilization when fuel density increases (due to reduced RVP) include air/fuel ratio shift to slightly richer, worse cylinder-to-cylinder A/F distribution, and increase of A/F excursions on transients. No quantitative estimates for the effect of these contributing factors is supplied by Ford, GM, or Professor Longwell. However, losing forty percent of the net energy increase seems an excessive amount for the combined effect of these losses. Thus, an R value of 0.6 would appear to be more appropriately used as a lower bound rather than a best estimate. However, a more appropriate figure cannot be identified in this approach. Therefore, another approach must be taken to determine the effect of increased energy content on vehicular fuel economy. This second approach is described below.

In determining the effect of a reduction in gasoline RVP on vehicular fuel economy, it is necessary to evaluate the vehicle that will be operating on this lower RVP fuel, and the design optimization of that vehicle. Automobile manufacturers are concerned with obtaining the highest fuel economy possible to meet CAFE requirements and advertise high fuel economies to attract consumers. Vehicular fuel economy figures are the result of testing over the EPA FTP and HFET cycles, in which the vehicles are operated on Indolene, a 9-psi RVP gasoline. Therefore, the manufacturers presumedly optimize the vehicle fuel systems to operate on Indolene, to maximize the fuel economy figures resulting from the FTP test cycle. As a result, vehicles probably are not optimized to operate in the field on commercial (in-use) gasoline with significantly higher vapor pressure and lower energy density. Operating on a fuel more like Indolene would, presumedly, be more efficient, than on a different fuel for which the vehicle was not optimized. This would argue that "R" may actually be greater than 1.0, though to what extent is unknown.

While Longwell states than an "ideal" engine would be expected to have an R value slightly less than 1.0, the situation Longwell refers to is not the same situation which is being evaluated here. Longwell's letter addresses more the issue of a vehicle optimized to run on a given fuel, and then run instead on a denser fuel; resulting in lower efficiency. In-use RVP reduction creates a circumstance in which an engine that is operating at less than maximum efficiency on gasoline other than what it was specifically designed for is now operated on a gasoline for which it was designed. Thus, Longwell's analysis does not apply specifically to this scenario, and the theoretical "R" value of 1.0 or more suggested above still appears the most reasonable. Thus, it will be used below to estimate the fuel economy credit associated with in-use volatility control. However, a lower bound R of 0.6 will also be examined to estimate the sensitivity of the study's results to this parameter.

C. Overall Relationship Between Gasoline Volatility and Fuel Economy

Combining the relationship between fuel volatility and energy density (from the Bonner and Moore study) with our best estimate for the relationship between energy density and fuel economy yields the overall relationship between fuel volatility and fuel economy. Energy density is projected to increase 0.25 percent with a 1-psi reduction in RVP and 0.56 percent with a 2-psi reduction in RVP. Vehicles should take full advantage of this increase in energy density to achieve a resultant increase in fuel economy. Thus, for both feedback and non-feedback equipped vehicles, the increase in fuel economy for 1- and 2-psi reductions in RVP would be 0.25 and 0.56 percent, respectively. The fuel economy effects for other RVP reductions were derived, by fitting a curve through these fuel economy increase values for 1- and 2-psi RVP reductions and are shown in Table 4-11. The lower bound estimates using an R of 0.6 are also shown in Table 4-11.

These fuel economy increases were used to evaluate a dollar credit resulting from gasoline RVP control. This credit was determined by multiplying the percent increase in fuel economy by the total number of gallons of gasoline consumed by

Table 4-11

Fuel Economy Effect of RVP Control

RVP Reduction (psi)	Percent Increase in Fuel Economy	
	Best Estimate R = 1.0	Lower Bound R = 0.6
0.5	0.11	0.066
1.0	0.25	0.150
1.5	0.40	0.240
2.0	0.56	0.336
2.5	0.73	0.438

motor vehicles, and then valuing that gasoline at $0.98 per gallon. This value was determined by subtracting a consumption-weighted state fuel tax of $0.13 per gallon and the Federal tax of $0.09 per gallon from the 1984 national-average retail gasoline price of $1.20 per gallon.[14] In other words, the consumer would be able to travel additional miles on the high energy, low RVP gasoline, and is thus credited the dollar value of the gasoline he would otherwise have had to purchase in order to travel those extra miles made available by the resulting high vehicular fuel economy.

VI. Economic Credit From Evaporative HC Recovery/Prevention

There are three major sources of evaporative hydrocarbon emissions that are associated with gasoline RVP. They are stationary source emissions (such as bulk storage terminal breathing losses, bulk transfer losses, and service station losses from transfer and underground tank breathing), refueling emissions, and motor vehicle evaporative emissions. The emission reductions for each of these sources associated with RVP control are detailed in Chapter 5 of this study. However, in addition to representing an environmental benefit, these emission reductions also represent an economic benefit in that these HC emissions are now available to be consumed as fuel by the motor vehicle (i.e., current emissions due to high volatility fuel represent a cost to the economy). The same is true for certification fuel RVP control, although only emission reductions from motor vehicles are relevant there. The methodology used to evaluate this cost credit resulting from the recovery and prevention of evaporative HC emissions via both fuel and vehicle control is outlined below.

The reductions in evaporative HC emissions from stationary sources, refueling, and motor vehicles (as described in Chapter 5) are used directly to determine the mass of HC now usable that would otherwise be lost if excess evaporative emissions were not controlled. This tonnage of hydrocarbons is converted to an equivalent volume using the density (lb/gal) of the hydrocarbons. Because the lighter hydrocarbons evaporate first, the specific gravity and energy densities (Btu/gal) of those hydrocarbons no longer lost to evaporation are significantly less than those of gasoline. As a first-order estimate, the evaporative hydrocarbons were all assumed to be butanes. The equivalent volume (gallons) of butane saved by RVP reduction is converted to energy using butane's energy content. This energy is then converted to equivalent gallons of gasoline, using a representative gasoline energy content figure (Btu/gallon). This volume of gasoline is then converted to a dollar amount using a value of $0.98 per gallon of gasoline. Overall, the value of a ton of evaporative emissions (butane) controlled or prevented is $335.26. The estimates for densities, energy densities, and gasoline value are summarized in Table 4-12.

Table 4-12

Estimates for Evaluating the Evaporative Recovery/ Prevention Credit Resulting from RVP Control

Description	Units	Estimate
Composition of Evap. Emissions		100% Butane
Density of Butane[15]	lb/gal	4.77
Energy Density of Butane[15]	Btu/lb Btu/gal	19,500 93,100
Energy Density of Gasoline[15]	Btu/lb Btu/gal	18,500 114,000
Value of Gasoline	$/gal	0.98
Value of Controlled/Prevented Evap. Emissions (Butane)	$/ton	335.26

VII. Overall Cost of In-Use Gasoline RVP Control

The overall cost of volatility control of in-use gasoline is the difference between the refinery cost of gasoline RVP control (Section III) and the credits due to increased vehicular fuel economy from 1) greater energy content of low RVP gasoline and 2) internal engine combustion of HCs otherwise lost to evaporation if RVP were not controlled (Sections V and VI). Subtracting these credits from Bonner and Moore's refinery cost of RVP control results in the net costs discussed below.

The aggregate costs of RVP control of in-use gasoline in 1988 (when only fuel control is relevant) are presented in Table 4-13, for both 12-month and 4-month control periods. Costs for RVP control during a 4-month period are simply one third those of 12-month control period. This ignores any shifts in wintertime butane supply which might be caused by shifts in summertime butane usage (e.g., storage of butane in the summer would increase winter supplies, while the use of butane as a petrochemical feedstock in the summer could increase such demand for butane in the winter). The short-term costs shown assume that there is not sufficient time for refineries to invest in new equipment for more economic means of controlling RVP. These costs, as well as those for the long term, are used in determining the cost effectiveness figures of Chapter 6.

These costs are dependent on several assumptions described earlier in this chapter. Should further analysis currently being conducted prove any of these assumptions incorrect, the results of the recent analysis will be incorporated in the cost calculations, and the costs will be revised accordingly. The major areas being further investigated are: 1) the effect on refining costs of controlling the percent of gasoline evaporated at 160°F, 2) the value of refinery equipment purchased specifically for gasoline volatility control during periods of the year without volatility restrictions, 3) the sensitivity of gasoline refinery costs to the availability of butane and alkylation capacity, 4) the cost of refinery gasoline specifically to be blended with ethanol, and 5) the effect on the ethanol industry of no longer permitting the "splash" blending of ethanol and gasoline. The results of studies in these areas will be used to revise these cost estimates as necessary as soon as they are available.

Table 4-13

Net Costs of Short-Term In-Use RVP Control:
1988 No Investment Case (millions of 1984 dollars per year)

	12-Month Control			
Level of RVP Control (psi)	Refinery Costs	Fuel Economy Credit	Evap. Recovery Credit	Net Cost
0.5	286	79	96	111
1.0	624	180	182	262
1.5	1028	287	256	485
2.0	1439	402	321	716
2.5	1880	523	379	978

	4-Month Control			
Level of RVP Control (psi)	Refinery Costs	Fuel Economy Credit	Evap. Recovery Credit	Net Cost
0.5	95	26	32	37
1.0	208	60	60	88
1.5	343	96	85	162
2.0	480	134	107	239
2.5	627	175	127	325

References (Chapter 4)

1. "Estimated Refining Cost Impact of Reduced Gasoline Vapor Pressure," Final Report, Bonner and Moore Management Science under SwRI Work Assignment #28 of EPA Contract No. 68-03-3162, July 1985.

2. Memorandum, "Transmittal of Draft Work Assignment #13 Contract 68-03-3192," Craig Harvey, Project Officer, TSS, ECTD, OMS, EPA, and Cooper Smith, Technical Project Monitor, SDSB, ECTD, OMS, EPA, to Albert W. Ahlquist, Contract Specialist, NCB, CMD, EPA, July 15, 1985.

3. Draft Supplemental Report to "Estimated Refining Cost Impact of Reduced Gasoline Vapor Pressure," Bonner and Moore, October 4, 1985.

4. "The Butane Industry: An Overview and Analysis of the Effects of Gasoline Volatility Control on Prices and Demand," Draft Report, Jack Faucett Associates, Work Assignment #5, EPA Contract No. 68-03-3244, May 30, 1985.

5. Memorandum, "Transmittal of Change 1 to Work Assignment #6 Contract 68-03-3244," Robert J. Johnson, Project Officer, SDSB, ECTD, OMS, EPA, to Paul S. Eninger, Contracting Officer, NCB, CMD, EPA, July 15, 1985.

6. Harry Weaver, Director, Environmental Department, Motor Vehicle Manufacturers Association, letter to Charles Gray, Director, ECTD, OMS, EPA, December 4, 1984.

7. Ronald L. Jones, American Petroleum Institute, letter to Charles L. Gray, Jr., Director ECTD, OMS, EPA, December 17, 1984.

8. W.S. Freas, Manager, Emission and Fuel Economy Operations, General Motors, letter to R.E. Maxwell, Director, Cert. Division, OMS, EPA, August 15, 1984.

9. J.C. Ingomells, Chevron Research Company, "Fuel Economy and Cold-Start Driveability with Same Recent Model Cars", SAE Paper No. 740522.

10. T.M Fisher, Director, Automotive Emission Control, General Motors Corporation, letter to EPA, Central Docket Section (LE-131), Docket A-83-44, January 22, 1985.

11. D.R. Buist, Director, Automotive Emissions and Fuel Economy Office, Environmental and Safety Engineering Staff, Ford, letter to Richard D. Wilson, Director, OMS, EPA, January 22, 1984.

References (Chapter 4) cont'd

12. Fred W. Bowditch, Motor Vehicle Manufacturers Association, letter to Richard D. Wilson, OMS, EPA, January 22, 1985.

13. John P. Longwell, Professor of Chemical Engineering, Massachusetts Institute of Technology, letter to Marvin W. Jackson, Environmental Activities Staff, General Motors Technical Center, January 16, 1985.

14. From Department of Energy, Monthly Energy Review, March 1985, as published in the National Petroleum News 1985 Factbook, p. 101.

15. Technical Data Book, API, Volume 4, 1983.

CHAPTER 5

Environmental Impact

I. Introduction

This chapter examines the environmental impact associated with each of the evaporative hydrocarbon (HC) control scenarios described in Chapter 2: 1) long-term control of in-use and certification fuel volatilities to equal levels (via changes to one or both); and, 2) additional short-term control of in-use RVP to levels lower than the long-term specifications for both fuels under 1) above.

The first section following this introduction (Section II) presents motor vehicle evaporative emission factors, by model year, for each of the RVP scenarios. Next, Section III reviews the effect of RVP control on exhaust emissions, while Section IV deals with the effect of in-use RVP control on evaporative losses from gasoline storage and distribution sources. Section V presents projected non-methane hydrocarbon (NMHC) emissions inventories under the various long- and short-term control scenarios, evaluating future nationwide inventories and also emissions in the 47 non-California urban areas currently in violation of the NAAQS for ozone (0.125 ppm).* This is followed (in Section VI) by an ozone air quality analysis of these same urban areas, comparing relative ozone violations under the various NMHC control strategies. Finally, the last section (VII) examines the effect of RVP control on levels of toxic emissions (i.e., benzene and gasoline vapors).

II. Motor Vehicle Evaporative HC Emission Factors

As described in Chapter 2, evaporative HC emissions from motor vehicles originate from two basic components of the vehicle's fuel system -- the fuel tank and the carburetor. The "diurnal" portion of the certification test simulates the vehicle's exposure to daily cyclic temperature variations which cause evaporative losses from the fuel tank to occur as the gasoline vapors expand in response to ambient temperature increases. The "hot-soak" portion of the certification test simulates emissions which occur just after the engine has been turned off, when residual engine and exhaust system heat causes the evaporation of fuel remaining in the carburetor bowl, as well as from the fuel tank and fuel lines. Total per-vehicle evaporative HC losses are represented by the sum of the hot-soak and diurnal emissions, and are expressed in terms of grams/test.* However, for air quality modelling purposes, the hot-soak and diurnal emissions are treated separately, since diurnal emissions occur once per day, but hot-soak emissions occur once per vehicle trip. Thus, the hot-soak emissions are multiplied by the number of trips per day and then added to the diurnal emissions. The sum is then divided by the number of vehicle miles travelled per day to yield an emission factor in terms of grams per mile (g/mi).

---

* As the California Air Resources Board (CARB) currently regulates in-use RVP in California, the seven California cities currently in non-attainment of the ozone NAAQS are not included in the city-specific analysis.

For the evaporative emission control scenarios described in Section VI of Chapter 2, the derivation of light-duty vehicle (LDV) evaporative emission factors can most easily be separated into four parts, differentiating between certain model year groups. The first section of Part A below addresses post-1989 LDVs in the case where in-use RVP equals the certification fuel RVP (long-term control scenarios); the 1990 model year is assumed to be the first to be affected by changes to certification fuel and/or test procedure. The second section addresses these same model years where in-use RVP is below the certification fuel RVP (short-term, additional in-use RVP control). The third section addresses 1981-1989 model year LDVs operating on various in-use RVP fuels (both long- and short-term scenarios); these vehicles will be designed for 9.0 psi, so their emission rates will only be affected by in-use RVP control. The fourth section addresses pre-1981 model year LDVs under various in-use RVP levels (same scenarios); again, these vehicles are designed for 9.0-psi fuel, but would be operating on various in-use RVPs.

The derivation of light-duty truck (LDT) and heavy-duty vehicle (HDV) emission factors is based almost entirely on the LDV data.[1] This derivation is briefly discussed in Section B following the development of the LDV rates.

A. Light-Duty Vehicles

1. Post-1989 LDVs: In-Use RVP = Certification RVP

Both vehicle- and fuel-related control strategies can apply to 1990 and later model year vehicles. Under the long-term strategy, commercial fuel RVP and certification fuel RVP will be made equal at some level between 9 and 11.5 psi, inclusive.

As discussed in more detail in Chapter 2 (Section V), motor vehicle evaporative emissions can, conceptually, be attributed to five sources: 1) properly designed and operated systems; 2) insufficient design of the purge system; 3) malmaintenance and equipment defects; 4) commercial fuel RVP in excess of certification fuel RVP; and 5) evaporative control system tampering. Below, the effect of RVP on each of these sources will be considered. The quantitative inputs and results for post-1989 vehicles are summarized in Tables 5-1 and 5-2, which draw upon the emission levels categorized in Section V of Chapter 2 (Table 2-15). As explained there, the derivation of these emission rates are based on data generated as part of EPA's ongoing in-use emission factor (EF) test program.

---

* Specific test procedures are outlined in Part 86 of the Code of Federal Regulations, and are reviewed in Section V of Chapter 2.

Vehicles with properly designed and operated systems are assumed to emit at the standard level, which is 2 grams/test for LDVs and LDTs, 3 grams/test for lighter HDVs, and 4 grams/test for heavier HDVs. This portion of the emission factor would not be affected by either fuel- or vehicle-oriented control, as indicated in Tables 5-1 and 5-2. These assumed standard levels were split into diurnal and hot-soak portions using the ratios of diurnal and hot-soak emissions to total emissions from problem-free EF LDVs.

The effect of improper design of the purge system is estimated as the difference between the average emissions of problem-free EF LDVs and the standard levels described above. This effect is assumed to disappear with a revised (i.e., improved) evaporative emission test procedure that could likely include, at a minimum, the saturation of the canister prior to testing. Thus, emissions due to improper design are shown as zero under the control scenarios in Tables 5-1 and 5-2.

The effect of malmaintenance and defects was shown in Chapter 2 to be dependent only upon in-use RVP. It was estimated as the difference between emissions from non-tampered EF vehicles and problem-free EF vehicles operated on various RVPs. Since this effect represents an in-use problem not likely to be eliminated by changing the certification test procedure (barring design standards or an improved durability test), it remains. This effect's dependence on in-use RVP is indicated in Tables 5-1 and 5-2.

The RVP effect was shown in Chapter 2 to be due to the differences between certification and in-use RVPs, and was calculated by subtracting non-tampered vehicle emissions on Indolene from emissions of non-tampered vehicles operating on commercial (11.5-psi) fuel.* As certification and in-use RVPs are assumed to be equal under the long-term strategies, this RVP effect disappears in new vehicles, as indicated in Tables 5-1 and 5-2.

Finally, the tampering effect is much like the effect of malmaintenance and defect in that it remains after the long-term strategy is imposed, but its magnitude is reduced by lowering in-use RVP. However, unlike the other effects, tampering rates are dependent upon vehicle mileage and are not constant with model year (i.e., there is a zero-mile rate plus a deterioration factor per every 10,000 miles). Therefore, MOBILE3 handles tampering separately and the tampering portion of emissions is not shown in Tables 5-1 through 5-4. Tampering offsets, calculated by subtracting total non-tampered emissions from uncontrolled emissions measured with disabled vehicles, were presented for various RVPs in Appendix 2-B of Chapter 2, along with details on the methodology used.

Also shown in Tables 5-1 and 5-2 are the breakdown of baseline emissions from these post-1989 vehicles; they represent levels estimated for the case where in-use RVP = 11.5 psi and certification RVP = 9.0 psi. The overall control efficiencies of the various RVP scenarios (expressed as percent-reductions from baseline emission levels) are also shown in the tables.

2. Post-1989 LDVs: Additional Short-Term In-Use RVP Control

As in the previous section, this control strategy is examined with respect to the five components of evaporative emissions from motor vehicles. Controlling in-use RVP to a level lower than the long-term certification RVP is assumed to have no effect on properly designed and operating vehicles since these vehicles are already assumed to be emitting at the standard. The improper design/purge and RVP sources are also not affected since they are already assumed to be zero. However, the malmaintenance/defect and tampering sources would be affected, since these are dependent only on in-use RVP. Thus, the total non-tampered diurnal and hot-soak emission rates for these vehicles, respectively, can be determined from Tables 5-1 and 5-2 by choosing the RVP column corresponding to the short-term in-use RVP level. In other words, the long-term

---

* However, as part of the RVP impact has already been accounted for in the malmaintenance/defect effect (shown to be dependent upon in-use RVP), this RVP effect is an adjusted figure (i.e., the difference between malmaintenance/defect at Indolene and 11.5-psi commercial fuel has been subtracted from the total difference between non-tampered emissions at Indolene and 11.5-psi commercial fuel). (See Appendix 2-B in Chapter 2 for more details.)

Table 5-1

Diurnal Emissions from Non-Tampered Post-1989 LDVs Under Long-Term Control Scenarios (g/test)

		Certification = In Use RVP (psi)					
	Baseline*	9.0	9.5	10.0	10.5	11.0	11.5
Carbureted Vehicles							
Properly Designed and Operated**	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Improper Design**	0.30	0.00	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect**	1.61	1.11	1.21	1.31	1.41	1.51	1.61
Excess RVP**	6.19	0.00	0.00	0.00	0.00	0.00	0.00
Total	9.01	2.02	2.12	2.22	2.32	2.42	2.52
Reduction from Baseline (%)	-	78	76	75	74	73	72
Fuel-Injected Vehicles							
Properly Designed and Operated**	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Improper Design**	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect**	0.84	0.34	0.44	0.54	0.64	0.74	0.84
RVP**	3.76	0.00	0.00	0.00	0.00	0.00	0.00
Total	5.51	1.25	1.35	1.45	1.55	1.65	1.75
Reduction from Baseline (%)	-	77	76	74	72	70	68

---

* "Baseline" indicates in-use RVP = 11.5 psi, certification RVP = 9.0 psi.

** From Table 2-15 in Chapter 2.

Table 5-2

Hot-Soak Emissions from Non-Tampered Post-1989 LDVs Under Long-Term Control Scenarios (g/test)

		Certification = In-Use RVP (psi)					
	Baseline*	9.0	9.5	10.0	10.5	11.0	11.5
Carbureted Vehicles							
Properly Designed and Operated**	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Improper Design**	0.40	0.00	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect**	1.24	0.83	0.91	0.99	1.07	1.15	1.24
Excess RVP**	1.11	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.84	1.92	2.00	2.08	2.16	2.24	2.33
Reduction from Baseline (%)	-	50	48	46	44	42	39
Fuel-Injected Vehicles							
Properly Designed and Operated**	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Improper Design**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect**	0.93	0.29	0.42	0.55	0.67	0.80	0.93
Excess RVP**	0.29	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.83	0.90	1.03	1.16	1.28	1.41	1.54
Reduction from Baseline (%)	-	51	44	37	30	23	16

---

* "Baseline" indicates in-use RVP = 11.5 psi, certification RVP = 9.0 psi.

** From Table 2-15 in Chapter 2.

certification RVP level is irrelevant here because the remaining effects are dependent on in-use RVP alone. The tampering offsets under these short-term control scenarios are again the same as those used in the long-term analysis under the appropriate in-use RVP level.

3. 1981-1989 LDVs: In-Use RVP Control

These vehicles are all certified to meet the 2-gram standard on Indolene regardless of the control scenario. Thus, their emissions depend only on in-use RVP. Derivation of their emissions is separated from pre-1981 models since significantly more data exists for these later models. (Emission factors for the older models are derived in the next section using the more recent-model data.)

As these pre-1990 vehicles will not be affected by certification fuel or test procedure modifications, their emissions can be estimated using current test results. For non-tampered vehicles, the average emission levels of the EPA EF program can be used directly. Implicit in these totals are the various effects of improper purge system design, malmaintenance/defects and RVP. Tampering is, as usual, considered separately. The non-tampered diurnal and hot-soak emission rates for 1981-89 models, respectively, and their reduction from baseline levels are shown in Tables 5-3 and 5-4.

4. Pre-1981 LDVs: In-Use RVP Control

Evaporative emissions estimates for pre-1981 LDVs operating on 11.5-psi fuel were derived for MOBILE3, based on limited test data, in mid-1984.[1] Since that time, API has tested 14 1978-80 vehicles (certified to the 6-gram SHED standard) on both Indolene and commercial fuels.[2] In general, API's results on both Indolene and the commercial fuels show higher emissions than those of EPA's EF program (see Table 5-5), but the API vehicle mileage is over 3 times higher, possibly explaining the difference. For MOBILE3, the 6-gram SHED emissions were assumed to equal the 2-gram SHED emissions because Indolene data on both sets of cars showed very similar results. While the API sample included only 14 vehicles, these results represent actual test data at reasonable mileages. Thus, the API data for 1978-80 vehicles appear more representative and have been substituted for the original MOBILE3 estimates.

API's tests were conducted only on models from 1978-80. Given the lack of any new data on pre-1978 vehicles, the MOBILE3 estimates for these earlier models have been retained for this analysis.

Table 5-3

Diurnal Emissions from Non-Tampered 1981-1989 LDVs Under In-Use RVP Control Scenarios (g/test)

		In-Use RVP (psi)					
	Baseline*	9.0	9.5	10.0	10.5	11.0	11.5
Carbureted Vehicles							
Non-Tampered Vehicle Total	9.01	2.32	3.04	4.06	5.40	7.05	9.01
Reduction from Baseline (%)	-	74	66	55	40	22	0
Fuel-Injected Vehicles							
Non-Tampered Vehicles Total	5.51	1.25	1.59	1.93	2.34	3.68	5.51
Reduction from Baseline (%)	-	77	71	65	58	33	0

---

* "Baseline" indicates in-use RVP = 11.5 psi, certification RVP = 9.0 psi.

Table 5-4

Hot-Soak Emissions from Non-Tampered 1981-1989 LDVs Under In-Use RVP Control Scenarios (g/test)

		In-Use RVP (psi)					
	Baseline*	9.0	9.5	10.0	10.5	11.0	11.5
Carbureted Vehicles							
Non-Tampered Vehicle Total	3.84	2.32	2.46	2.68	2.98	3.37	3.84
Reduction from Baseline (%)	-	40	36	30	22	12	0
Fuel-Injected Vehicles							
Non-Tampered Vehicle Total	1.83	0.90	1.08	1.27	1.46	1.65	1.83
Reduction from Baseline (%)	-	51	41	31	20	10	0

---

* "Baseline" indicates in-use RVP = 11.5 psi, certification RVP = 9.0 psi.

Table 5-5

Evaporative Emissions Testing on Non-Tampered 1978-1980 LDVs

Fuel RVP	Test Program	No. of Vehicles Tested	Mean Odometer (Miles)	Emissions (g/test)	
				Hot Soak	Diurnal
9.0	EF	124	14,100	2.27	3.08
9.0	API	14	49,040	2.44	5.16
10.5	EF	--	--	--	--
10.5	API	14	49,040	2.81	9.77
11.5	EF*	--	--	3.98	9.31
11.5	API**	14	49,040	3.29	15.12

---

* Original MOBILE3 figures.

** Revised MOBILE3 figures (API's test data).

5. Summary of LDV Emission Factors

The resulting non-tampered LDV evaporative emission rates, in terms of g/test, under the various RVP control scenarios are shown in Table 5-6. Here, the carbureted and fuel-injected LDV emission rates shown in Tables 5-1 through 5-5 are weighted together based on MOBILE3 model-year sales projections.[1] For both the long-term and short-term control strategies, the emission rates can be determined by choosing the appropriate in-use RVP scenario.

B. Light-Duty Trucks and Heavy-Duty Vehicles

The MOBILE3 evaporative emission estimates for LDT_1s (6000 lbs. GVW* and less) are essentially the same as those for LDVs.[1] This is based on: 1) the fact that the emission standards -- 6 and 2 grams in 1978 and 1981, respectively -- are the same for both LDVs and LDT_1s, and 2) that early EF testing of LDVs and LDT_1s on Indolene showed similar results. However, pre-1979 LDTs having a GVW over 6,000 lbs, now designated LDT_2s, were previously classified as heavy-duty vehicles (HDVs); their MOBILE3 emission factors are, thus, the same as the HDV rates described below. Post-1978 emission factors for LDT_2s are the same as those for LDT_1s and LDVs in MOBILE3.

Because no new LDT data were available for this study, the MOBILE3 methodology was retained. The changes made to the LDV data (discussed earlier) are also reflected in the LDT estimates used. These LDT_1 and LDT_2 emission factors are summarized in Tables 5-7 and 5-8, respectively. The post-1980 figures in the tables differ from the LDV rates in Table 5-6 only because of different carbureted/fuel-injected sales weightings[1]; the individual rates, if shown, would be the same as the individual carbureted and fuel-injected LDV estimates.

The situation is entirely analogous for HDVs. No new HDV data are currently available and the MOBILE3 estimates were in part based on LDV emissions.[1] Thus, the MOBILE3 methodology is again used here, but with the revised LDV estimates. The HDV emission rates used in this study are summarized in Table 5-9.

---

* Rated "gross vehicle weight".

Table 5-6

Non-Tampered LDV Evaporative HC Emission Rates Under Various RVP Control Scenarios (grams/test)

Model Year	In-use Fuel RVP (psi)*											
	9.0		9.5		10.0		10.5		11.0		11.5	
	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.
Low Altitude												
pre-1971	14.67	26.08	16.22	30.46	17.78	34.84	19.34	39.22	20.89	43.61	22.45	47.99
1971	10.91	16.28	11.38	18.69	12.13	22.13	13.17	26.61	14.50	32.12	16.15	38.58
1972-77	8.27	8.98	8.63	10.55	9.22	12.80	10.02	15.72	11.05	19.31	12.32	23.53
1978-80	2.44	5.16	2.52	6.24	2.64	7.77	2.81	9.77	3.03	12.23	3.29	15.12
1981	2.18	2.21	2.33	2.90	2.54	3.86	2.84	5.12	3.21	6.73	3.65	8.68
1982	2.06	2.12	2.20	2.77	2.42	3.68	2.70	4.84	3.05	6.43	3.47	8.37
1983	1.93	2.02	2.08	2.64	2.29	3.48	2.56	4.56	2.89	6.12	3.29	8.04
1984	1.75	1.89	1.91	2.46	2.11	3.21	2.37	4.18	2.68	5.70	3.04	7.61
1985-86	1.45	1.66	1.62	2.15	1.82	2.77	2.05	3.54	2.32	5.00	2.62	6.87
1987-89	1.19	1.47	1.36	1.89	1.56	2.37	1.77	2.97	2.00	4.37	2.24	6.22
1990+	1.01	1.34	1.14	1.44	1.26	1.54	1.38	1.64	1.51	1.74	1.63	1.84
High Altitude												
pre-1971	19.07	33.90	21.09	39.60	23.11	45.30	25.14	50.99	27.16	56.69	29.18	62.38
1971	14.18	21.16	14.79	24.30	15.77	28.77	17.13	34.59	18.85	41.75	20.99	50.16
1972-76	14.07	17.15	14.69	20.15	15.68	24.44	17.05	30.02	18.80	36.88	20.96	44.93
1977	8.27	8.98	8.63	10.55	9.22	12.80	10.02	15.72	11.05	19.31	12.32	23.53
1978-80	6.32	13.36	6.52	16.15	6.84	20.13	7.28	25.31	7.84	31.68	8.53	39.16
1981	5.66	5.74	6.03	7.51	6.59	10.01	7.35	13.25	8.30	17.44	9.46	24.47
1982	2.68	2.76	2.87	3.60	3.14	4.78	3.51	6.30	3.97	8.36	4.51	10.88
1983	2.50	2.63	2.70	3.43	2.97	4.52	3.33	5.93	3.76	7.96	4.27	10.45
1984+	(Same as Low Altitude)											

---

* Certification fuel RVP is assumed to be 9.0 psi for all pre-1990 model years; 1990 and later vehicles are assumed to be designed for an RVP equal to the in-use level (i.e., certification RVP = in-use RVP beginning in 1990).

Table 5-7

Non-Tampered LDT_1 Evaporative HC Emission Rates Under Various RVP Control Scenarios (grams/test)

Model	In-use Fuel RVP (psi)*											
	9.0		9.5		10.0		10.5		11.0		11.5	
Year	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.
Low Altitude												
pre-1971	14.67	26.08	16.22	30.46	17.78	34.84	19.34	39.22	20.89	43.61	22.45	47.99
1971	10.91	16.28	11.38	18.69	12.13	22.13	13.17	26.61	14.50	32.12	16.15	38.58
1972-77	8.27	8.98	8.63	10.55	9.22	12.80	10.02	15.72	11.05	19.31	12.32	23.53
1978-80	2.44	5.16	2.52	6.24	2.64	7.77	2.81	9.77	3.03	12.23	3.29	15.12
1981-83	2.32	2.32	2.46	3.04	2.68	4.06	2.98	5.40	3.37	7.05	3.84	9.01
1984	2.09	2.14	2.24	2.80	2.45	3.72	2.74	4.91	3.09	6.51	3.52	8.45
1985	1.86	1.97	2.02	2.57	2.23	3.38	2.49	4.42	2.82	5.97	3.20	7.89
1986	1.64	1.80	1.80	2.34	2.00	3.04	2.25	3.93	2.54	5.43	2.88	7.33
1987	1.44	1.65	1.60	2.14	1.80	2.74	2.04	3.51	2.30	4.96	2.60	6.84
1988-89	1.19	1.47	1.36	1.89	1.56	2.37	1.77	2.97	2.00	4.37	2.24	6.22
1990+	1.01	1.34	1.14	1.44	1.26	1.54	1.38	1.64	1.51	1.74	1.63	1.84
High Altitude												
pre-1971	19.07	33.90	21.09	39.60	23.11	45.30	25.14	50.99	27.16	56.69	29.18	62.38
1971	14.18	21.16	14.79	24.30	15.77	28.77	17.13	34.59	18.85	41.75	20.99	50.16
1972-76	14.07	17.15	14.69	20.15	15.68	24.44	17.05	30.02	18.80	36.88	20.96	44.93
1977	8.27	8.98	8.63	10.55	9.22	12.80	10.02	15.72	11.05	19.31	12.32	23.53
1978-81	6.32	13.36	6.52	16.15	6.84	20.13	7.28	25.31	7.84	31.68	8.53	39.16
1982-83	3.01	3.01	3.19	3.95	3.48	5.28	3.87	7.02	4.38	9.17	4.99	11.71
1984	2.72	2.79	2.91	3.65	3.19	4.84	3.56	6.39	4.02	8.47	4.57	10.98
1985	2.42	2.57	2.62	3.35	2.89	4.40	3.24	5.75	3.66	7.77	4.16	10.25
1986	2.13	2.34	2.34	3.04	2.60	3.96	2.92	5.11	3.30	7.07	3.74	9.52
1987	1.87	2.15	2.09	2.78	2.35	3.57	2.65	4.56	2.99	6.45	3.37	8.89
1988-89	1.54	1.91	1.77	2.45	2.03	3.08	2.30	3.86	2.60	5.69	2.92	8.09
1990+	1.31	1.74	1.48	1.87	1.64	2.00	1.79	2.13	1.96	2.26	2.12	2.39

---

* Certification fuel RVP is assumed to be 9.0 psi for all pre-1990 model years; 1990 and later vehicles are assumed to be designed for an RVP equal to the in-use level (i.e., certification RVP = in-use RVP beginning in 1990).

Table 5-8

Non-Tampered LDT$_2$ Evaporative HC Emission Rates Under Various RVP Control Scenarios (grams/test)

Model	In-use Fuel RVP (psi)*											
	9.0		9.5		10.0		10.5		11.0		11.5	
Year	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.
Low Altitude												
pre-1979	18.08	42.33	20.00	49.44	21.91	56.55	23.83	63.66	25.75	70.78	27.66	77.89
1979-80	2.44	5.16	2.52	6.24	2.64	7.77	2.81	9.77	3.03	12.23	3.29	15.12
1981-83	2.32	2.32	2.46	3.04	2.68	4.06	2.98	5.40	3.37	7.05	3.84	9.01
1984	2.09	2.14	2.24	2.80	2.45	3.72	2.74	4.91	3.09	6.51	3.52	8.45
1985	1.86	1.97	1.02	2.57	2.23	3.38	2.49	4.42	2.82	5.97	3.20	7.89
1986	1.64	1.80	1.80	2.34	2.00	3.04	2.25	3.93	2.54	5.43	2.88	7.33
1987	1.44	1.65	1.60	2.14	1.80	2.74	2.04	3.51	2.30	4.96	2.60	6.84
1988-89	1.19	1.47	1.36	1.89	1.56	2.37	1.77	2.97	2.00	4.37	2.24	6.22
1990+	1.01	1.34	1.14	1.44	1.26	1.54	1.38	1.64	1.51	1.74	1.63	1.84
High Altitude												
pre-1979	23.50	55.03	26.00	64.27	28.49	73.52	30.98	82.76	33.47	92.01	35.96	101.25
1979-81	6.32	13.36	6.52	16.15	6.84	20.13	7.28	25.31	7.84	31.68	8.53	39.16
1982-83	3.01	3.01	3.19	3.95	3.48	5.28	3.87	7.02	4.38	9.17	4.99	11.71
1984	2.72	2.79	2.91	3.65	3.19	4.84	3.56	6.39	4.02	8.47	4.57	10.98
1985	2.42	2.57	2.62	3.35	2.89	4.40	3.24	5.75	3.66	7.77	4.16	10.25
1986	2.13	2.34	2.34	3.04	2.60	3.96	2.92	5.11	3.30	7.07	3.74	9.52
1987	1.87	2.15	2.09	2.78	2.35	3.57	2.65	4.56	2.99	6.45	3.37	8.89
1988-89	1.54	1.91	1.77	2.45	2.03	3.08	2.30	3.86	2.60	5.69	2.92	8.09
1990+	1.31	1.74	1.48	1.87	1.64	2.00	1.79	2.13	1.96	2.26	2.12	2.39

---

* Certification fuel RVP is assumed to be 9.0 psi for all pre-1990 model years; 1990 and later vehicles are assumed to be designed for an RVP equal to the in-use level (i.e., certification RVP = in-use RVP beginning in 1990).

Table 5-9

Non-Tampered HDV Evaporative HC Emission Rates
Under Various RVP Control Scenarios (grams/test)

Model Year	In-use Fuel RVP (psi)* 9.0		9.5		10.0		10.5		11.0		11.5	
	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.
Low Altitude												
pre-1985	18.08	42.33	20.00	49.44	21.91	56.55	23.83	63.66	25.75	70.78	27.66	77.89
1985-1989	3.69	3.69	3.91	4.83	4.26	6.47	4.75	8.60	5.36	11.23	6.11	14.34
1990+	3.06	3.22	3.19	3.38	3.32	3.54	3.45	3.70	3.57	3.86	3.70	4.02
High Altitude												
pre-1985	23.50	55.03	26.00	64.28	28.49	73.52	30.98	82.76	33.47	92.01	35.96	101.25
1985-1989	4.80	4.79	5.08	6.28	5.54	8.42	6.17	11.19	6.97	14.60	7.95	18.65
1990+	3.98	4.19	4.15	4.39	4.32	4.60	4.49	4.81	4.64	5.02	4.81	5.23

---

* Certification fuel RVP is assumed to be 9.0 psi for all pre-1990 model years; 1990 and later vehicles are assumed to be designed for an RVP equal to the in-use level (i.e., certification RVP = in-use RVP beginning in 1990).

III. Motor Vehicle Exhaust Emission Factors

As discussed in detail in Chapter 2, EPA's in-use EF testing indicates that fuel RVP has an effect on exhaust HC and CO emissions from current vehicles; no effect on NOx emissions was shown to be present.[3] This effect on HC and CO emissions appears to be basically linear with RVP and was accounted for in this analysis by applying multiplicative factors for each RVP scenario to the original MOBILE3 exhaust emission factors published in June 1984. These multiplicative adjustment factors are shown in Tables 5-10 and 5-11 for HC and CO, respectively.* The "base" case in the tables, as before, refers to an in-use RVP of 11.5 psi and a certification fuel RVP of 9.0 psi (current); the other RVP scenarios (11.5 down to 9.0 psi) indicate the long-term control options where in-use RVP is assumed to equal certification fuel RVP (beginning with the 1990 model year).

Original MOBILE3 exhaust emission factors (published in June 1984) were based on an in-use RVP of roughly 11.5 psi and a certification fuel RVP of 9.0 psi, which represents the baseline RVP scenario. Therefore, no exhaust adjustment is necessary under the base case, as indicated by the factors of 1.00 in Tables 5-10 and 5-11. Also, no adjustment is necessary for those model year vehicles that were not equipped with evaporative control systems (i.e., pre-1971 LDGVs and $LDGT_1$s, pre-1979 $LDGT_2$s, and pre-1985 HDGVs). This is based on the conclusion made in Chapter 2 that the RVP effect on exhaust HC and CO is related to the purging of the evaporative canister and not to the combustion of fuel inducted via the carburetor; therefore, no adjustment is made for these model years, regardless of RVP level (i.e., the original MOBILE3 estimates are used).

As is the case with all in-use EF testing, the exhaust emissions effect was measured only for vehicles whose evaporative control systems were designed for Indolene (9.0 psi) and operated on fuels of various RVPs. These data were used to develop the exhaust adjustment factors at each RVP level shown in Tables 5-10 and 5-11 for the pre-1990 models. As shown, no adjustment is necessary for these vehicles under the 11.5-psi RVP scenario, as these pre-1990 model years still

---

* Although adjustment factors for both HC and CO are presented, the remainder of the study focuses only on non-methane hydrocarbons. The possible CO benefits achievable with in-use RVP control were not incorporated into this study, but could enter into cost effectiveness calculations in future analyses.

Table 5-10

Exhaust HC Adjustment Factors*

Model Years	RVP Scenarios (psi)						
	Base	11.5	11.0	10.5	10.0	9.5	9.0
LDGV							
pre-1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1971-80	1.000	1.000	0.991	0.982	0.973	0.965	0.956
1981-89	1.000	1.000	0.969	0.938	0.907	0.877	0.846
1990+	1.000	0.846	0.846	0.846	0.846	0.846	0.846
$LDGT_1$							
pre-1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1971-83	1.000	1.000	0.991	0.982	0.973	0.965	0.956
1984-89	1.000	1.000	0.969	0.938	0.907	0.877	0.846
1990+	1.000	0.846	0.846	0.846	0.846	0.846	0.846
$LDGT_2$							
pre-1979	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1979-83	1.000	1.000	0.991	0.982	0.973	0.965	0.956
1984-89	1.000	1.000	0.969	0.938	0.907	0.877	0.846
1990+	1.000	0.846	0.846	0.846	0.846	0.846	0.846
HDGV							
pre-1985	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1985-89	1.000	1.000	0.991	0.982	0.973	0.965	0.956
1990+	1.000	0.956	0.956	0.956	0.956	0.956	0.956

---

* To be multiplied by June 1984 MOBILE3 exhaust HC factors.

Table 5-11

Exhaust CO Adjustment Factors*

	RVP Scenarios (psi)						
Model Years	**Base**	**11.5**	**11.0**	**10.5**	**10.0**	**9.5**	**9.0**
LDGV							
pre-1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1971-80	1.000	1.000	0.985	0.970	0.955	0.939	0.924
1981-89	1.000	1.000	0.962	0.924	0.886	0.848	0.809
1990+	1.000	0.809	0.809	0.809	0.809	0.809	0.809
LDGT$_1$							
pre-1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1971-83	1.000	1.000	0.985	0.970	0.955	0.939	0.924
1984-89	1.000	1.000	0.962	0.924	0.886	0.848	0.809
1990+	1.000	0.809	0.809	0.809	0.809	0.809	0.809
LDGT$_2$							
pre-1979	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1979-83	1.000	1.000	0.985	0.970	0.955	0.939	0.924
1984-89	1.000	1.000	0.962	0.924	0.886	0.848	0.809
1990+	1.000	0.809	0.809	0.809	0.809	0.809	0.809
HDGV							
pre-1985	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1985-89	1.000	1.000	0.985	0.970	0.955	0.939	0.924
1990+	1.000	0.924	0.924	0.924	0.924	0.924	0.924

---

* To be multiplied by June 1984 MOBILE3 exhaust CO factors.

represent the baseline case (designed for 9.0 psi); however, this is not the case for 1990 and later vehicles which, under the long-term control scenarios, would be designed for the in-use fuel RVP.

As concluded in Chapter 2, the effect of in-use RVP on exhaust emissions is assumed to be eliminated if vehicles are operated on the same RVP fuel for which they were designed (i.e., in-use RVP equal to certification RVP). Therefore, in all of the long-term strategies examined in this chapter, original MOBILE3 exhaust emission factors estimated for post-1989 vehicles are adjusted by the same factor as that calculated for the 9.0-psi RVP scenario for the preceding model year group, which was designed for 9.0 psi. In other words, the level of in-use fuel RVP is irrelevant as long as it is equal to certification fuel RVP. The adjustment factor shown in Tables 5-10 and 5-11 for 1989 vehicles (designed for 9.0 psi) under the 9.0-psi in-use RVP scenario is representative of this situation and is, therefore, assumed to apply to all 1990 and later models as well, except of course for the baseline case where no change in certification fuel is made.

IV. Effect of In-Use RVP Control on Gasoline Storage and Distribution Losses

While this study focuses primarily on the non-compliance of in-use motor vehicles with the current evaporative standards, one of the strategies being considered to control this evaporative excess would also have an impact on emissions from stationary sources. As the levels of evaporative HCs emitted during the storage and handling of gasoline are a function of true vapor pressure (which is dependent upon RVP), the control of in-use gasoline volatility would affect the level of emissions from these sources. Of course, the other strategies being examined (changes to certification fuel and test procedure) would have no impact on these stationary sources as they involve only a change in the design of new vehicles.

The following sections deal with the effect of in-use RVP control on each of three basic categories of gasoline storage and distribution losses: 1) bulk storage and bulk transfer losses, 2) service station (Stage I) emissions, and 3) vehicle refueling losses. Evaporative emission rates for these sources are commonly expressed in terms of grams of HC vapor lost per gallon of gasoline stored or transferred.

A. Bulk Storage and Transfer Losses

This first category consists mainly of breathing and working (i.e., loading and unloading) losses resulting from the storage of gasoline in bulk terminals and the transfer of gasoline to tankers, ships, and barges used for transport. Emission rates associated with bulk storage are dependent upon various factors such as tank configuration (fixed or floating roof), tank dimensions, ambient and liquid storage temperatures, and vapor molecular weight and true vapor pressure (both dependent upon the RVP of the gasoline). Emissions incurred during the loading of cargo carriers are dependent upon the method of filling (submerged or splash), bulk temperature of liquid, and the RVP-dependent parameters mentioned above. Equations defining specific types of evaporative losses (e.g., breathing, loading) as a function of these and other parameters were developed for various types of storage and transport mediums and were published in EPA's AP-42 Document.[4]

The impact of controlling in-use fuel volatility on evaporative emissions from the bulk storage and transfer of gasoline was determined using the various AP-42 equations. Holding the non-fuel-related parameters in the equations constant, it was estimated that a reduction in in-use RVP from 11.5 to 9.0 psi would result in a 20-28 percent decrease in evaporative losses from bulk storage terminals (magnitude dependent upon tank configuration and type of loss -- breathing, working, or standing).[4] With respect to cargo loading, the same decrease in RVP should reduce evaporative losses by approximately 20 percent.[4] Inventories for the various types of losses in the bulk storage and transfer category were adjusted by the appropriate factors and were incorporated into this analysis under all control strategies involving the regulation of in-use fuel volatility. Estimates for the intermediate in-use RVP scenarios (e.g., 10.0, 11.0 psi) were derived through linear interpolation between the inventories associated with the 9.0- and 11.5-psi options.

B. Service Station (Stage I) Losses

This second stationary category includes the breathing and loading losses associated with underground storage facilities at service stations. Losses in this category are sometimes referred to as "Stage I," designating emissions between the tank truck and the service station. Emission rates from these sources are primarily based on the same parameters as the breathing and loading losses described in the previous section.

As before, the estimated reduction in Stage I losses resulting from a 2.5-psi decrease in in-use fuel RVP is between 20 and 28 percent.[4] In this analysis, Stage I emissions were handled as one broad category and an estimated 23-percent reduction was assumed for the 9.0-psi in-use RVP scenario; as before, emissions for the intermediate in-use RVP scenarios were developed using linear interpolation.

C. Refueling Losses

Refueling losses refer to the vapors that escape into the atmosphere while dispensing gasoline from a service station pump into a vehicle's fuel tank. The refueling emission rate is dependent upon the RVP of the fuel, the dispensed temperature of the fuel, and the temperature differential between the dispensed fuel and the liquid already in the tank. In support of pending EPA actions regarding the control of refueling emissions (the onboard versus "Stage II" issue), extensive tests were conducted to determine the relationship between refueling emission levels (in terms of grams per gallon of fuel dispensed) and the above parameters. The derivation of an equation relating these parameters is documented in an EPA technical report.[5]

In order to determine (for this analysis) the effect of in-use RVP reductions on uncontrolled refueling emissions, the equation developed from the refueling test data was used. Assuming nationwide average summertime conditions -- dispensed temperature 9.4°F less than fuel tank temperature, with a dispensed temperature of 78.8°F -- the impact of in-use RVP control was determined. In addition to the displacement losses calculated with the refueling equation, a spillage factor of 0.3 g/gal (5-6 percent of the total refueling loss), which is unaffected by RVP, was also included in the overall emission factors. With a reduction in RVP from 11.5 psi to 9.0 psi, the uncontrolled refueling emission rate under the above temperature conditions is estimated to decrease from 6.0 to 4.8 grams/gallon, or by 20 percent. As the equation used to calculate these refueling rates is linear, values for each of the intermediate RVP control scenarios were determined through interpolation.

D. Non-RVP-Related Controls

Regardless of whether in-use RVP control is implemented, EPA, states and local areas have established equipment-related controls for stationary sources that must be accounted for in modelling future hydrocarbon emissions. The Clean Air Act as amended in 1977 requires that hydrocarbon emissions from both new and existing stationary sources in ozone non-attainment areas be controlled to the lowest achievable levels; EPA has interpreted this as those levels achievable with "reasonably available control technology" (RACT), which varies from source to source. To assist the states in developing control regulations consistent with RACT levels, EPA's Office of Air Quality Planning and Standards (OAQPS) issued, in the late 1970's, several control technique guideline (CTG) documents relevant to various sources associated with the gasoline marketing industry.[6-11] These CTGs assessed the technology available to control HC emissions from various sources such as bulk storage terminals, gasoline tank trucks, loading operations, etc., and provided estimates of the emission rates achievable with the RACT level of control.

The Clean Air Act Amendments of 1977 also stated that all areas were to be in compliance with the ozone NAAQS by 1982; therefore, this date was originally projected as the year by which RACT levels of control would be fully implemented on HC sources in the non-attainment areas of the late 1970's and 1980's. In anticipation of full implementation by 1982, RACT began being applied to some sources (primarily new sources) following publication of the CTGs in 1977 and 1978. However, RACT was not fully implemented by 1982 and indeed is not fully in place at the time of this analysis; as outlined earlier, an estimated 54 urban areas are currently out of compliance and 35 have requested an extension of the attainment date to 1987. For purposes of this analysis, it was assumed that RACT would be fully implemented by 1988, which is the earliest projection year examined in this report.

The emissions control efficiencies and source growth and retirement (or replacement) rates to be assumed in modelling future HC emissions from these stationary sources were evaluated in a 1980 EPA report.[12] Using the RACT-based emission rates outlined in the CTGs, it was estimated that the HC emissions reduction achievable with full implementation of RACT was roughly 80 percent in both the bulk storage/transfer and Stage I categories.[12] The net growth and replacement rates (respectively) for both of these categories, based on projections of future earnings in the petroleum industry, were estimated at 1.9 and 4.5 percent per year, compounded annually.[12]

The control efficiencies estimated above are applicable only to base emissions at the pre-RACT level typical of the late 1970's (when the CTGs were published). The HC emissions projections made for this analysis were based on the NEDS* inventory for 1982, a year by which some sources had already been controlled to the RACT level. Between 1978 and 1982, limited implementation of RACT resulted in a reduction of approximately 14-15 percent in average emission rates from bulk storage and transfer sources and an almost negligible 4 percent in Stage I losses (measured from 1978 levels).[13] This partial implementation of RACT was accounted for in this analysis by modifying the control efficiencies used in the model. Instead of applying the 80-percent control recommended for both categories, a 76-percent reduction from average 1982 bulk storage/transfer emission rates was estimated to be achievable with full implementation of RACT; for the Stage I category, the recommended control efficiency was reduced to 79 percent to account for the slight implementation of RACT in this area.

---

* NEDS is the National Emissions Data System, from which emissions inventories are compiled by EPA's National Air Data Branch within OAQPS; the most recent inventory available at the time of this analysis was for calendar year 1982.

V. Hydrocarbon Emissions Inventory Analysis

MOBILE3 is EPA's current model for estimating calendar-year fleet-average emission factors for various gaseous pollutants. In calculating evaporative HC emission factors (included in total non-methane hydrocarbons, or NMHCs) for this analysis, the model-year hot-soak and diurnal losses estimated earlier for each of the various control strategies serve as inputs to MOBILE3. Within the model, these evaporative losses (in terms of grams/test) are converted to grams/mile using estimates of average trips made and miles driven each day. The June 1984 version of MOBILE3 assumed that these values were constant over all model years, but recent work supports the theory that older vehicles make fewer trips and travel less miles than new vehicles.[14] Because this is probably more realistic than the assumptions within the originally published MOBILE3, inputs for miles/day and trips/day have been revised and were used to calculate the evaporative emission factors used in this analysis.

Emissions inventories for various source categories were then calculated for the nation (excluding California) and for the 47 non-California urban areas that are currently in non-attainment of the ozone NAAQS.* (The specific cities were listed earlier in Table 2-1 of Chapter 2.) All future projections are based on the 1982 NEDS inventory for volatile organic carbons (VOCs), or NMHCs. To the motor vehicle portions of this inventory are applied annual compound VMT growth rates (calculated for each vehicle class via the MOBILE3 Fuel Consumption Model, or FCM) and emission factor ratios (future to base year) from the MOBILE3 runs. Projections of stationary source emissions are based on the annual growth and retirement rates, along with emission control efficiencies, discussed in the previous section. Of course, the stationary sources that contribute to evaporative HC emissions (gasoline storage and distribution) have been the focus above, since they are affected by fuel RVP, but all sources of NMHC emissions have been included in the modeling with their respective growth, retirement, and control estimates.[12]

---

* Nationwide inventories were converted to non-California inventories assuming that California accounts for approximately 11 percent of total nationwide emissions. This figure is fuel-consumption based, so may not necessarily apply to all stationary sources. However, because the control programs will affect only gasoline-related sources, the 11-percent figure was applied to all entire inventories to put the emissions reductions in the proper perspective.

Baseline NMHC emissions inventories were calculated assuming that an in-use RVP of 11.5 psi and a certification fuel RVP of 9.0 psi would continue through the year 2010; these inventories will be presented along with those for the control cases in the tables discussed in the following sections. To put the various sources of NMHC emissions into perspective, a breakdown of future total baseline emissions is presented graphically in Figures 5-1a and 5-1b for calendar years 1988 and 2010. In Figure 5-1a, the inventories are broken down into six categories: motor vehicle evaporative losses, motor vehicle exhaust emissions, refueling, Stage I, bulk storage, and others (consisting of off-highway and non-gasoline-related stationary sources). As shown, the "others" category is the largest in both years, representing approximately 61-72 percent of total NMHC emissions. Motor vehicle emissions (evaporative, exhaust, and refueling losses) make up roughly 24-36 percent of the total. The lower end of the range is representative of 2010, as motor vehicle emissions will decrease with time in response to evaporative and exhaust HC standards and improved fuel economies (used to convert refueling losses from g/gal to g/mi).

Figure 5-1b breaks motor vehicle evaporative emissions down further into the five components discussed in detail in Chapter 2 (Section V). These sources of evaporative losses are: properly designed vehicles (meeting the standards), improper design of purge system, malmaintenance/defects, excess in-use RVP, and evaporative system tampering. As indicated in Figure 5-1b, the RVP effect is the largest of the five, contributing to approximately 35 percent of total evaporative losses.

The following inventory discussion begins with estimates of future NMHC emissions under the long-term control scenarios -- in-use RVP equal to certification fuel RVP, at various

Figure 5-1a
Non-Calif. NMHC Inventory--Baseline (11.5-psi RVP)

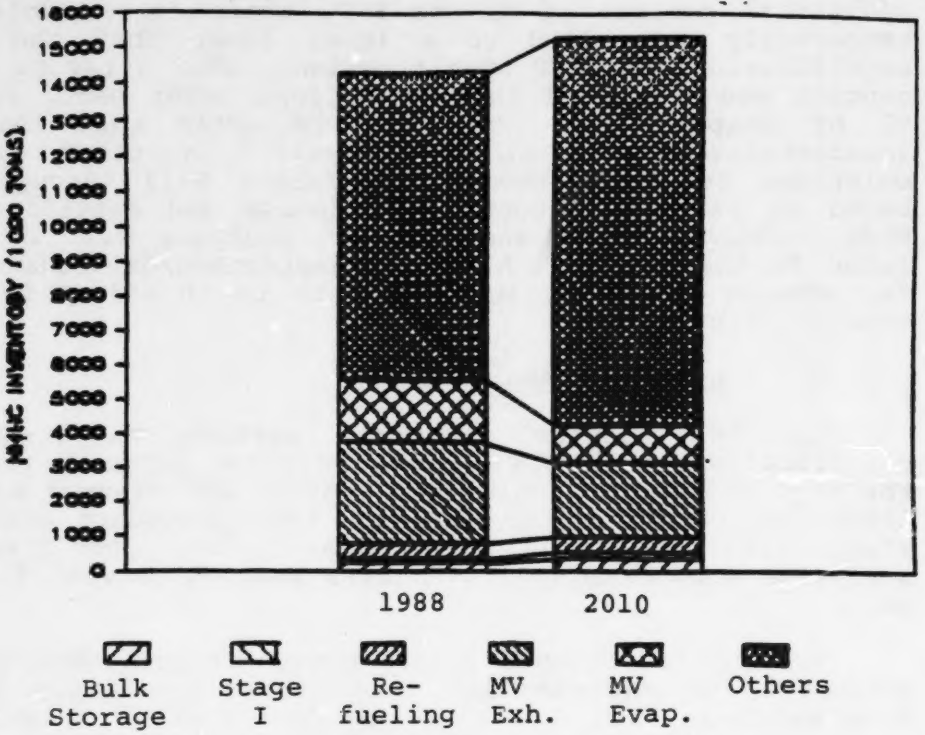
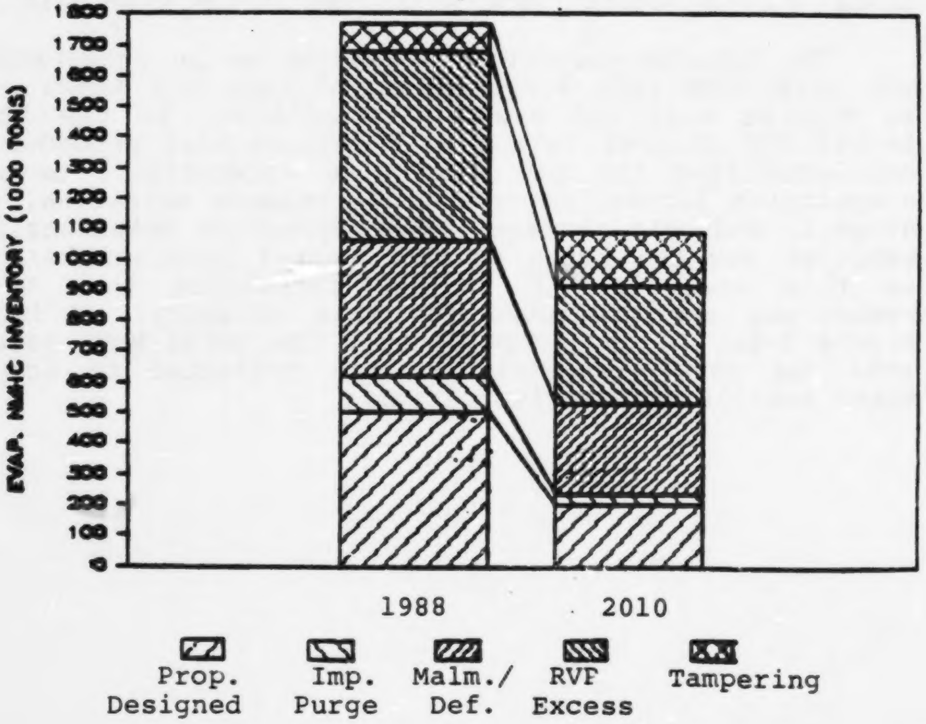


Figure 5-1b
Non-Calif. MV Evap. Inventory--Baseline (11.5-psi RVP)



volatility levels. The next section focuses on the short-term additional control of in-use RVP, where in-use volatility is temporarily controlled to a level lower than the long-term certification fuel RVP specification. (For a review of the two control scenarios and the RVP options under each, see Section VI of Chapter 2.) It should be noted that this chapter incorporates a year-round analysis; in other words, the emissions results presented in Tables 5-12 through 5-15 are based on year-round control of in-use and certification fuel RVPs. (Both 4-month and 12-month analyses will be presented later in Chapter 6.) Also, an inspection/maintenance program for exhaust emissions is assumed to be in effect in all areas through 2010.

A. Long-Term Analysis

Long-term control involves changes to in-use and/or certification fuel RVPs to make the two equal to each other. For this analysis, in-use fuel control was assumed to begin in 1988, and certification fuel and test procedure changes would start with the 1990 model year. Six long-term control scenarios were examined, with RVPs ranging between 9.0 and 11.5 psi.

Table 5-12 presents future non-California NMHC inventories estimated for the baseline case (shown previously in Figures 5-1a and 5-1b) and the six long-term control strategies. As shown, the control of in-use RVP to a level of 9.0 psi, while holding certification fuel RVP at its current 9.0 psi, results in the largest change -- almost a 7-percent reduction in total annual non-California NMHC emissions in the year 2010.

The tonnage reductions estimated to be achievable in 1988 and 2010 with this 9.0-psi control case are shown graphically in Figures 5-2a and 5-2b. As indicated in the top figure, in-use RVP control (along with revised test procedure) reduces emissions from the following five categories: motor vehicle evaporative losses, motor vehicle exhaust emissions, refueling, Stage I, and bulk storage. As evaporative emissions from motor vehicles are the focus of the control programs being examined in this analysis, it is not surprising that the largest reductions are predicted for this category; as indicated in Figure 5-2a, 72 and 62 percent of the total NMHC reductions in 1988 and 2010, respectively, are projected to occur in the motor vehicle evaporative category.

Table 5-12

Non-California NMHC Emissions Inventories Under Long-Term Control Options*

Scenario	RVP (psi)	NMHC, 1000 tons/year(% Reduction) 1988	1995	2010
B	Baseline case **	14,307(0)	13,350(0)	15,298(0)
1	11.5	14,307(0)	13,125(1.7)	14,714(3.8)
2	11.0	14,024(2.0)	12,958(2.9)	14,629(4.4)
3	10.5	13,769(3.8)	12,807(4.1)	14,543(4.9)
4	10.0	13,553(5.3)	12,676(5.1)	14,458(5.5)
5	9.5	13,360(6.6)	12,553(6.0)	14,374(6.0)
6	9.0	13,191(7.8)	12,439(6.8)	14,288(6.6)

---

* California emissions, roughly 11 percent of nationwide total, were excluded. Long-term control assumes in-use RVP and certification fuel RVP will be equal, beginning in 1990; in-use fuel changes would occur in 1988, followed by certification fuel changes in 1990; year-round RVP control is assumed.

** Baseline case refers to the uncontrolled situation in ASTM's "Class-C" areas: in-use RVP at 11.5 psi and certification fuel RVP equal to 9.0 psi.

Figure 5-2a
Non-Calif. NMHC Reductions--RVP Control to 9.0 psi

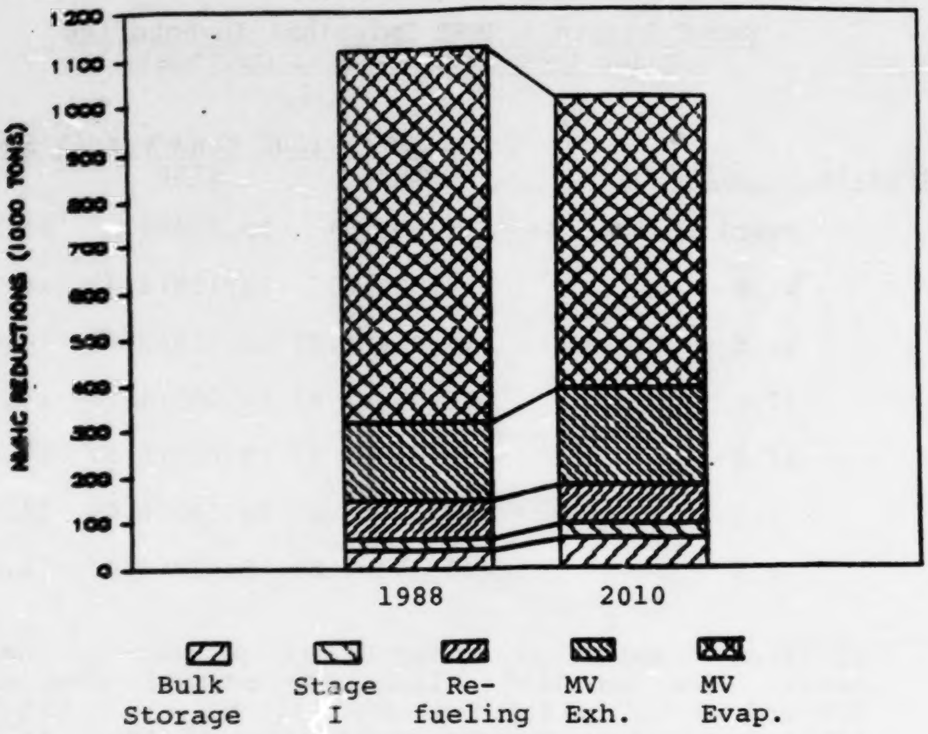
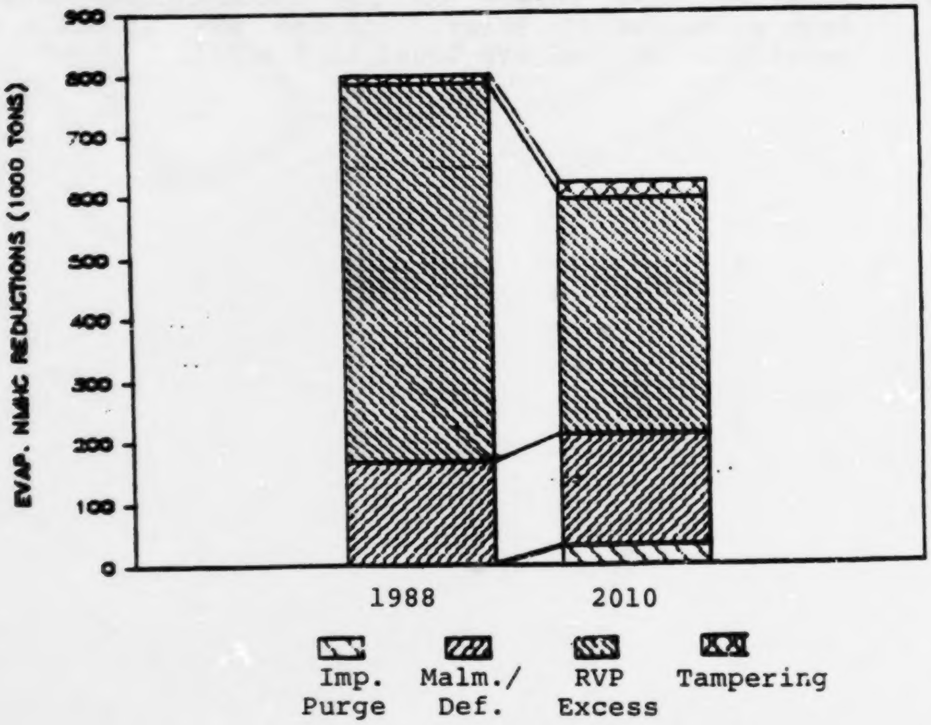


Figure 5-2b
Non-Calif. MV Evap. Reductions--RVP Control to 9.0 psi



In Figure 5-2b, these reductions in motor vehicle evaporative emissions are broken down further into the various components shown earlier (in Figure 5-1b). Of the five original sources, reductions occur in only three in 1988 and four in 2010. Emissions from properly designed vehicles will not be reduced, as these vehicles are assumed to meet the evaporative standards; therefore, this category does not appear in Figure 5-2b. A second category -- improper purge design -- is not included in the 1988 emissions reductions because the change in test procedure that would address this problem would not be implemented until 1990; therefore, this component does contribute to the reductions in the year 2010. As indicated in the figure, the largest reductions are achievable in the excess RVP category -- 61-77 percent of motor vehicle evaporative HC reductions are predicted to occur here. This is understandable, in part, because excess RVP is the largest source of total motor vehicle evaporative losses (as indicated previously in Figure 5-1b).

Combined inventories for the 47 ozone non-attainment areas examined are presented in Table 5-13. These non-California urban areas (listed in Chapter 2) consist of 45 low-altitude and 2 high-altitude SMSAs. Similar to the nationwide analysis, a 2.5-psi reduction in in-use RVP (from the current 11.5 down to 9.0 psi) would reduce year 2010 emissions in these 47 urban areas by an estimated 7-8 percent.

B. Short-Term Analysis

Tables 5-14 and 5-15 show future non-California and 47-city NMHC emissions inventories, respectively, estimated for the various short-term RVP scenarios. As the RVP combinations listed in these tables indicate, this short-term strategy involves temporary additional control of in-use RVP to a level lower than the long-term certification specification. As with the long-term scenario, in-use and certification changes are assumed to take place, respectively, in 1988 and 1990. While the certification fuel specification would continue indefinitely, the in-use control would be relaxed after a specified period of time and in-use and certification RVPs would become equal. Several time periods for this short-term control were evaluated; scenarios of 2, 4, 7, and 9 years (represented by 1990, 1992, 1995, and 1997) are shown in the tables. Of course, the inventories presented are applicable only if additional in-use control is in place during the calendar years shown; following the relaxation of in-use control to the long-term certification fuel level, annual inventories would be those estimated for the long-term strategy under the appropriate RVP scenario (in Tables 5-12 and 5-13).

Table 5-13

Combined NMHC Emissions Inventories for 47 Urban Areas Under Long-Term Control Options*

		NMHC, 1000 tons/year(% Reduction)		
Scenario	RVP (psi)	1988	1995	2010
B	Baseline case **	5077(0)	4693(0)	5465(0)
1	11.5	5077(0)	4601(2.0)	5229(4.3)
2	11.0	4960(2.3)	4534(3.4)	5193(5.0)
3	10.5	4855(4.4)	4472(4.7)	5158(5.6)
4	10.0	4767(6.1)	4418(5.9)	5122(6.3)
5	9.5	4688(7.7)	4368(6.9)	5087(6.9)
6	9.0	4620(9.0)	4322(7.9)	5051(7.6)

---

* Long-term control assumes in-use RVP and certification fuel RVP will be equal, beginning in 1990; in-use fuel changes would occur in 1988, followed by certification fuel changes in 1990; year-round RVP control is assumed.

** Baseline case refers to the uncontrolled situation in ASTM's "Class-C" areas: in-use RVP at 11.5 psi and certification fuel RVP equal to 9.0 psi.

Table 5-14

Non-California* NMHC Emissions Inventories With Short-Term Additional In-Use RVP Control

Scenario	Short-Term In-Use RVP (psi)	Long-Term Cert. Fuel RVP (psi)	NMHC (1000 tons/year) 1990	1992	1995	1997
B	Baseline (11.5)	Baseline (9.0)	13,821	13,513	13,350	13,397
1	9.0	9.5	12,795	12,550	12,439	12,504
2	9.0	10.0	12,795	12,550	12,439	12,504
3	9.5	10.0	12,950	12,687	12,553	12,608
4	9.0	10.5	12,795	12,550	12,439	12,504
5	9.5	10.5	12,950	12,687	12,553	12,608
6	10.0	10.5	13,124	12,838	12,676	12,715
7	9.0	11.0	12,795	12,550	12,439	12,504
8	9.5	11.0	12,950	12,687	12,553	12,608
9	10.0	11.0	13,124	12,838	12,676	12,715
10	10.5	11.0	13,320	13,004	12,807	12,828
11	9.0	11.5	12,795	12,550	12,439	12,504
12	9.5	11.5	12,950	12,687	12,553	12,608
13	10.0	11.5	13,124	12,838	12,676	12,715
14	10.5	11.5	13,320	13,004	12,807	12,828
15	11.0	11.5	13,553	13,200	12,958	12,957

---

* California emissions, roughly 11 percent of nationwide total, are excluded.

Table 5-15

Combined NMHC Emissions Inventories for 47 Urban Areas With Additional Short-Term In-Use RVP Control

Scenario	Short-Term In-Use RVP (psi)	Long-Term Cert. Fuel RVP (psi)	NMHC (1000 tons/year) 1990	1992	1995	1997
B	Baseline (11.5)	Baseline (9.0)	4877	4754	4693	4716
1	9.0	9.5	4459	4362	4322	4351
2	9.0	10.0	4459	4362	4322	4351
3	9.5	10.0	4522	4417	4368	4394
4	9.0	10.5	4459	4362	4322	4351
5	9.5	10.5	4522	4417	4368	4394
6	10.0	10.5	4593	4478	4418	4438
7	9.0	11.0	4459	4362	4322	4351
8	9.5	11.0	4522	4417	4368	4394
9	10.0	11.0	4593	4478	4418	4438
10	10.5	11.0	4671	4545	4472	4484
11	9.0	11.5	4459	4362	4322	4351
12	9.5	11.5	4522	4417	4368	4394
13	10.0	11.5	4593	4478	4418	4438
14	10.5	11.5	4671	4545	4472	4484
15	11.0	11.5	4767	4625	4534	4537

In comparing the inventories shown in short-term Tables 5-14 and 5-15 under different RVP strategies, it is important to note that the emissions totals shown are dependent only upon the short-term in-use RVP listed. In other words, the 1995 inventories shown in Table 5-14 for scenario #7 (in-use = 9.0, certification = 11.0) are the same as the 1995 figures shown in long-term Table 5-12 under scenario #6 (in-use = certification = 9.0). Inherent in this is the assumption that no emissions benefit will be derived from the "overdesign" of the canister for a higher RVP fuel (i.e., a vehicle designed for 11.0-psi fuel and operated on Indolene will emit the same amount as a vehicle both designed for and operated on Indolene). This assumption is best explained by referring to the five components of motor vehicle evaporative emissions discussed earlier in Section II of this chapter (and in more detail in Chapter 2).

As the source breakdowns in Tables 5-1 and 5-2 indicated, the RVP effect and the effect of improper design/purge are assumed to be totally eliminated if certification test procedure is revised and if certification RVP is raised to a level equal to in-use RVP; because these categories are totally eliminated when certification and in-use RVPs are made equal, no emissions benefit can be derived from designing the canister for an even higher RVP fuel. Of course, the emissions of properly designed and operated vehicles will not change (i.e., they will continue to emit at the evaporative standard level). The two remaining effects -- tampering and malmaintenance/defect -- are dependent only upon in-use RVP (i.e., the fact that certification RVP is higher than in-use RVP will have no impact on these essentially uncontrolled emissions). Therefore, short-term additional in-use RVP control provides the same emissions benefits as with the long-term scenario at that particular in-use RVP; the advantage is that the fleet is allowed to begin turning over with vehicles designed for the higher RVP to which in-use control will be relaxed after a specified period.

VI. Ozone Air Quality Analysis

Because of the complex relationship between ambient ozone concentrations and hydrocarbon emissions, the rollback approach used by EPA to model other pollutants (i.e., NOx and CO) is inappropriate for ozone. Instead, EPA makes use of the EKMA (Empirical Kinetic Modelling Approach) to predict future ambient ozone concentrations in specific urban areas. The EKMA utilizes a series of ozone isopleths which depict downwind ozone concentrations as a function of initial NMHC and NOx concentrations, subsequent NMHC and NOx emissions, meteorological conditions, reactivity of the precursor mix, and concentrations of ozone and precursors transported from upwind areas. It should be noted that the EKMA as used by EPA is a nationwide-average model. In other words, no city-specific information is input into the model except for the base-year ozone concentrations, or "design values," from which future concentrations are projected*; meteorological conditions, etc., are held constant for all the urban areas modelled. (Design values for the 47 cities in this analysis were shown in Table 2-1 of Chapter 2.[15] For more details on the EKMA, see References 16 and 17.)

Using EKMA and the NMHC emissions inventories presented in Tables 5-13 and 5-15, projections of future ozone conditions in the 47 current non-California non-attainment areas were made. The first section below focuses on future air quality in the long term, followed by a similar presentation with respect to short-term control alternatives.

A. Long-Term Analysis

Tables 5-16 through 5-18 present EKMA-based predictions of future ambient ozone conditions in 47 current non-attainment areas under the six long-term RVP scenarios. The first of these tables shows the average change in ambient ozone concentration with respect to the base level in 1982. The reductions expected to occur under the baseline RVP scenario are, of course, in response to programs other than gasoline volatility control, such as equipment-related stationary source HC controls and motor vehicle exhaust HC emissions standards. However, the additional ozone reductions shown under the six RVP scenarios in Table 5-16 are due solely to NMHC reductions through in-use and/or certification RVP control. For example, if in-use RVP was controlled to 10.0 psi in 1988 and certification RVP was raised to 10.0 psi in 1990, ambient ozone concentrations by the year 1995 would be expected to decrease an additional 5 percent beyond the baseline RVP scenario (i.e., 33 percent vs. 28 percent lower than 1982 levels).

Estimates of total annual violations of the ozone NAAQS are presented in Table 5-17 for each of the long-term RVP scenarios. The NAAQS for ozone sets a limit of 0.125 ppm for the fourth highest daily maximum 1-hour ozone concentration in any three-year period; the violations listed in the table represent the total number of days this maximum hourly ozone concentration is expected to exceed 0.125 ppm. Only the peak

---

* An area's "design value" is its fourth highest daily maximum one-hour ozone concentration recorded (for this analysis) during 1981, 1982, and 1983.

Table 5-16

Average Percentage Change* in Ambient Ozone Concentrations in 47 Urban Areas Under Long-Term Control Options

Scenario	RVP (psi)	1988	1995	2010
B	Baseline	-23	-28	-18
1	11.5	-23	-30	-21
2	11.0	-24	-31	-22
3	10.5	-26	-32	-22
4	10.0	-27	-33	-23
5	9.5	-28	-34	-23
6	9.0	-29	-34	-24

---

* With respect to base-year (1982) levels.

Table 5-17

Number of Total Annual Violations of Ozone NAAQS in 47 Urban Areas Under Long-Term Control Options

Scenario	RVP (psi)	1988	1995	2010
B	Baseline	67	46	96
1	11.5	67	35	76
2	11.0	60	34	76
3	10.5	55	31	74
4	10.0	51	29	70
5	9.5	48	26	67
6	9.0	39	25	66

monitoring site in each of the 47 areas was considered, so the maximum possible number of annual violations per area is 365. As Table 5-16 shows, for example, long-term scenario #6 (both RVPs equal to 9.0) is estimated to reduce the total number of ozone violations in the 47 cities combined by approximately 46 percent from the baseline RVP scenario in 1995 (i.e., 25 vs. 46 violations).

Finally, Table 5-18 estimates the total number of non-California urban areas expected to be in violation of the ozone NAAQS under the various long-term control options. As shown, scenario #6 is projected to enable roughly 6 more cities to come into attainment in 1988. One limitation associated with evaluating control options on the basis of number of non-attainment areas is that only those areas that fall below the NAAQS as a result of the action are distinguishable; in other words, the value of bringing an area closer to attainment is not recognized unless attainment is achieved. Therefore, estimated overall emissions reductions or changes in average ambient concentrations as a result of a particular action are probably more indicative of the environmental impact of the action than is the projected number of non-attainment areas.

B. Short-Term Analysis

Using EKMA and the NMHC emissions inventories presented earlier in Table 5-15, air quality projections were made under the various short-term RVP control scenarios. Results are presented (in the same form as for the long-term scenarios) in Tables 5-19 through 5-21. As before with the emissions inventories, the short-term air quality results presented here are basically dependent on in-use RVP; in other words, the short-term results at a particular in-use RVP level agree with the long-term projections at that same RVP.

VII. Effect of RVP Control on Toxic Emission Levels

This section analyzes how RVP control may influence the content of certain components in liquid gasoline and how these changes may affect emissions of benzene and other toxic compounds. The primary compounds of concern here are benzene and whole gasoline vapor, due to their known or suspected human carcinogenicity. Benzene has been listed as a hazardous pollutant under Section 112 of the Clean Air Act. The evidence of carcinogenicity of gasoline vapors comes primarily from the American Petroleum Institute's (API) chronic inhalation study in rats and mice.[18] The effect of vehicle-oriented RVP control will be addressed first, followed by that of fuel-oriented RVP control.

Table 5-18

Number of Ozone Non-Attainment Areas* Under Long-Term Control Options

Scenario	RVP (psi)	1982	1988	1995	2010
B	Baseline	47	14	8	16
1	11.5	47	14	6	12
2	11.0	47	13	6	12
3	10.5	47	13	6	12
4	10.0	47	11	6	12
5	9.5	47	10	6	11
6	9.0	47	8	6	11

---

* Non-California areas only.

Table 5-19

Average Percentage Change* in Ambient Ozone Concentrations In 47 Urban Areas With Additional Short-Term In-Use RVP Control

Scenario	Short-Term In-Use RVP (psi)	Long-Term Cert. Fuel RVP (psi)	1990	1992	1995	1997
B	Baseline (11.5)	Baseline (9.0)	-25	-27	-28	-28
1	9.0	9.5	-32	-34	-34	-34
2	9.0	10.0	-32	-34	-34	-34
3	9.5	10.0	-31	-33	-34	-33
4	9.0	10.5	-32	-34	-34	-34
5	9.5	10.5	-31	-33	-34	-33
6	10.0	10.5	-30	-32	-33	-33
7	9.0	11.0	-32	-34	-34	-34
8	9.5	11.0	-31	-33	-34	-33
9	10.0	11.0	-30	-32	-33	-33
10	10.5	11.0	-28	-31	-32	-32
11	9.0	11.5	-32	-34	-34	-34
12	9.5	11.5	-31	-33	-34	-33
13	10.0	11.5	-30	-32	-33	-33
14	10.5	11.5	-28	-31	-32	-32
15	11.0	11.5	-27	-29	-31	-31

---

* With respect to base year (1982) levels.

Table 5-20

Number of Total Annual Violations of Ozone NAAQS in 47 Urban Areas With Additional Short-Term In-Use RVP Control

Scenario	Short-Term In-Use RVP (psi)	Long-Term Cert. Fuel RVP (psi)	1990	1992	1995	1997
B	Baseline (11.5)	Baseline (9.0)	58	48	42	43
1	9.0	9.5	29	26	25	26
2	9.0	10.0	29	26	25	26
3	9.5	10.0	31	29	26	27
4	9.0	10.5	29	26	25	26
5	9.5	10.5	31	29	26	27
6	10.0	10.5	37	30	29	30
7	9.0	11.0	29	26	25	26
8	9.5	11.0	31	29	26	27
9	10.0	11.0	37	30	29	30
10	10.5	11.0	45	33	31	32
11	9.0	11.5	29	26	25	26
12	9.5	11.5	31	29	26	27
13	10.0	11.5	37	30	29	30
14	10.5	11.5	45	33	31	32
15	11.0	11.5	52	39	34	33

Table 5-21

Number of Ozone Non-Attainment Areas* With Additional Short-Term In-Use RVP Control

Scenario	Short-Term In-Use RVP (psi)	Long-Term Cert. Fuel RVP (psi)	1990	1992	1995	1997
B	Baseline (11.5)	Baseline (9.0)	13	10	8	9
1	9.0	9.5	6	6	6	6
2	9.0	10.0	6	6	6	6
3	9.5	10.0	6	6	6	6
4	9.0	10.5	6	6	6	6
5	9.5	10.5	6	6	6	6
6	10.0	10.5	6	6	6	6
7	9.0	11.0	6	6	6	6
8	9.5	11.0	6	6	6	6
9	10.0	11.0	6	6	6	6
10	10.5	11.0	8	6	6	6
11	9.0	11.5	6	6	6	6
12	9.5	11.5	6	6	6	6
13	10.0	11.5	6	6	6	6
14	10.5	11.5	8	6	6	6
15	11.0	11.5	11	7	6	6

---

* Non-California areas only.

A. Vehicle-Related RVP Control

Overall, the effect of vehicle-oriented RVP control on toxic emissions will be positive. Vehicle-oriented RVP control reduces evaporative HC emissions directly and does not affect the amount of vapors, toxic or benign, generated by the vehicle since the fuel is not affected. Since improvements in the capture and recycling of these vapors can only reduce emissions, and not increase them, the effect on toxic emissions can only be positive. For example, a saturated evaporative cannister will not efficiently capture any additional HC compounds sent to it. An increase in its size and improved purging will provide additional capacity to absorb both butane and higher compounds, such as benzene. No data are currently available showing the benzene content of evaporative emissions from current vehicles operating on commercial fuel both failing and meeting the evaporative emission standard, so this effect cannot be quantified. However, it definitely will reduce such emissions.

The effect of vehicle-oriented RVP control on exhaust emissions is only slightly more complex. The primary effect of vehicle improvements will be to improve the combustion of HC vapors recycled from the charcoal cannister. This should reduce the emissions of all HC compounds. A secondary effect will be that those toxic compounds now being emitted will be recycled to the engine, so their emissions may increase somewhat. However, the former effect should override the latter, since the amount of higher compounds, such as aromatics, being introduced to the engine via cannister purging will be very small compared to that introduced via the main fuel metering system. For example, even if purged fuel is 10 percent of total fuel consumption, which it can be under certain circumstances, the aromatic content of the purged fuel will be a small fraction of that of the liquid fuel, due to the low relative volatility of such compounds in the fuel tank (the primary source of evaporative emimissions on the dominant post-1990 vehicle technoloty, fuel-injection).

B. Fuel-Related RVP Control

The effect of fuel-oriented RVP control is more complex, because the composition of the fuel itself is changing. Few data are available with which to analyze this effect, which overall should be quite small since the fuel compositional changes are expected to be quite small. However, what data are available are used below to quantify this efect. The first section below estimates the effect of in-use RVP control on benzene emissions. The second section extrapolates these conclusions in order to estimate the effect on emissions of whole gasoline vapors.

1. Benzene Emissions

As already mentioned in Chapter 4, in-use control of RVP will be achieved primarily by reducing the quantity of butane in the gasoline pool by up to 5 percent (roughly 2 percent per 1.0 psi RVP reduction). If the quantity of butane in the fuel is reduced without any other compositional changes, the percentage of all other fuel constituents, including aromatics, would be expected to increase proportionately (i.e., by up to a factor of 1.05). However, other compositional changes are expected which will either heighten or mitigate this general increase. No data are available concerning the effect of RVP control on benzene levels, in particular, but projections are available from the Bonner and Moore model of total fuel aromatic content for the baseline and control cases allowing investment and open NGL purchases (see Table 5-22). As can be seen, the nationwide average aromatic content increases, additively, by 0.6 percent and 2.8 percent for RVP reductions of 1 psi and 2 psi, respectively, over the baseline level of 32.5 volume percent. Assuming benzene levels increase proportionately, then current benzene levels (roughly 1.34 percent based on the 1984 NIPER survey [19]) would increase 0.01 volume percent with a 1 psi RVP reduction and 0.04 volume percent with a 2 psi reduction.

Very limited data are also available which detail vehicle evaporative and exhaust benzene emissions as a function of fuel composition. The data available are from a study by EPA and are shown in Table 5-23.[20] The original data set consisted of 4 vehicles. However, two of the vehicles were omitted from this analysis since they were pre-1978 models and their evaporative control systems, by design, are quite inefficient and unrepresentative of current vehicle technology. Even the remaining two vehicles were certified to the 1978-1980 model year 6-gram evaporative HC standard and, therefore, do not fully represent more recent technology. However, their systems are conceptually very close to current technology and can be used here. With respect to exhaust emissions controls, these two vehicles were equipped with oxidation catalysts, air injection, and exhaust gas recirculation. Again, while not entirely representative of the feedback-controlled, three-way catalyst vehicles of today, the control systems were generally quite efficient (1.5 g/mi HC versus uncontrolled emissions of roughly 4 g/mi) and represent the best data available. The hot-soak and diurnal emissions shown in Table 5-23 were converted from gram per test to gram per mile using the original MOBILE3 equation shown below:

$$\text{Evap} = \frac{\text{Di} + (3.05\ \text{trips/day})(\text{Hs})}{31.1\ \text{miles/day}}$$

Table 5-22

Changes in Aromatic Content (Vol %) Resulting from RVP Control*

With Investment, Open NGLs

	PADD				
	1	2	3	4 + 5 (ex. CA)**	Total U.S. (ex. CA)***
Baseline					
Unleaded Regular	38.8	32.0	31.3	31.7	32.2
Unleaded Premium	31.6	37.9	31.0	34.5	33.3
Leaded Regular	30.8	31.2	34.6	32.9	33.1
Weigted Average	36.1	32.9	31.8	32.4	32.5
1 PSI RVP Reduction					
Unleaded Regular	37.9	33.1	31.2	32.2	32.4
Unleaded Premium	35.8	36.9	31.3	34.1	33.6
Leaded Regular	31.0	31.3	33.6	32.5	32.6
Weighted Average	36.3	33.5	31.6	32.6	32.7
2 PSI RVP Reduction					
Unleaded Regular	38.3	33.6	32.4	33.0	33.3
Unleaded Premium	36.0	35.6	34.5	35.1	35.0
Leaded Regular	31.1	31.5	32.2	31.9	31.9
Weighted Average	36.7	33.6	32.7	33.2	33.4

---

* As predicted by Bonner and Moore RPMS model.

** Estimated as an average of PADDs 2 and 3.

*** Total U.S. (ex. CA) estimated by volumetrically weighting of PADD aromatic content for PADDs 1,2,3,4 and 5 using PADD specific gasoline production.

[4] Average estimated by weighting the three gasoline grades by % of sales by volume.

Table 5-23

Effect of Fuel Composition on Benzene Emissions [20]

Test Vehicle: 1979 LTD

Test Code	Fuel Aromatic Vol %	Fuel Benzene Vol %	RVP psi	Tailpipe Benzene g/mi	Evaporative Benzene g/mi
B	43.4	1.5	9.8	.025	.007
B-1	46.6	7.1	9.8	.035	.020
C	25.7	2.0	12.3	.014	.011

Test Vehicle:1978 Monarch

Test Code	Fuel Aromatic Vol %	Fuel Benzene Vol %	RVP psi	Tailpipe Benzene g/mi	Evaporative Benzene g/mi
A	27.4	0.3	8.4	.030	.001
A-1	32.4	7.1	8.4	.058	.010
B	43.4	1.5	9.8	.030	.009
C	25.7	2.0	12.3	.033	.005

Evap = total evaporative emissions, grams/mile
Di = diurnal emissions, grams/test (one per day)
Hs = hot-soak emissions, grams/test (one per trip)

Ongoing research to determine the effect of fuel benzene concentration on exhaust and evaporative benzene emissions is currently being conducted by the Coordinating Research Council and should be published by the end of 1985. The results of this study (and any other data which becomes available) will be incorporated into this analysis as soon as the results are published.

The data of Table 5-23 show evaporative benzene emissions to primarily be dependent upon two variables; fuel benzene content and RVP. As would be expected, total aromatic content is not a factor, since the temperatures in both the fuel tank and fuel metering system are too low to produce benzene from other aromatics. Overall, as the benzene content of the fuel increases, evaporative benzene emissions increase. As RVP decreases, evaporative benzene emissions decrease. Estimates of the effect of unit changes in each of these two fuel properties on evaporative benzene emissions are presented in Table 5-24. The effect of fuel benzene content was determined for each vehicle separately (tests B and B-1 for the 1979 LTD and tests A and A-1 for the 1978 Monarch) and then averaged. The effect of RVP was determined for each of four pairs of tests (tests B and C for the LTD and tests A and B, A and C, and B and C for the Monarch) and then averaged. Many of the changes in RVP were also accompanied by changes in fuel benzene content. To account for this, the benzene effect determined for each vehicle was subtracted from the overall change in benzene emissions before determining the RVP effect. While the benzene effect was fairly similar for the two vehicles, the effect of RVP varied considerably. Thus, additional data would be particularly useful in improving this latter estimate.

The effect of fuel benzene content on exhaust emissions of benzene was determined in a similar fashion using tests B and B-1 for the LTD and tests A and A-1 for the Monarch. These tests represented the largest change in fuel benzene content and RVP and fuel aromatic content were relatively constant. The effects of both RVP and fuel aromatic content were impossible to estimate, however, as they tended to change together inversely. Thus, estimates of their effect will have to await the development of additional data.

The effect of these changes in benzene emissions per mile on nationwide emissions (non-California) are presented in Table 5-25. An estimate of total nationwide VMT was taken from EPA fuel consumption model and California was assumed to represent

Table 5-24

Effect of RVP Control on Benzene
Evaporative and Exhaust Emission Factors

Evaporative Emissions	
RVP	-.0013(g/mi)/1 psi RVP reduction
Benzene Effect	.0019(g/mi)/1 vol % Benzene Increase
Exhaust Emissions	
Benzene Effect	.0030(g/mi)/1 vol % Benzene Increase

Table 5-25

Change in 1988Non-California Benzene Emissions Due to RVP Control (Tons)

Source	Degree of RVP Control 1 psi reduction	 2 psi reduction
M.V. Evap.		
RVP Effect	-631	-1261
Benzene Effect	10	41
M.V. Exhaust		
Benzene Effect	17	69
Total	-604	-1151

11 percent of nationwide VMT, as discussed earlier in the chapter.[21] No attempt was made to estimate the difference between LDV, LDT and HDV emissions.

These results show that the RVP effect dominates the fuel benzene effect and an overall reduction in benzene evaporative emissions would be projected for in-use RVP control. Overall, these decreases represent 2 and 5 percent of current nationwide (non-California) benzene emissions of roughly 250,000 tons, respectively.[22,23].

Increased fuel benzene content occuring while reducing RVP may also affect refueling, Stage I, and bulk storage emissions of benzene. Lower total HC emissions should lower benzene emissions which are carried off by the evaporation of other compounds, while a higher fuel benzene content is likely to increase benzene concentration in the vapor that is emitted. No data showing which of these two effects dominates are available. Given the very slight projected increase in aromatic content (and presumedly, benzene content), any increase in benzene emissions due to increased benzene vapor concentration should be very small and the net change in benzene emissions even smaller.

B. Toxic Gasoline Vapors

The second toxic pollutant to be considered here is whole gasoline vapor. The API animal experiments used an aerosol formed from completely vaporized liquid gasoline.[18] However, the precise compounds producing the carcinogenic effects have yet to be identified. Therefore, all that can be said at this time is that, based on the small compositional changes expected to occur with in-use RVP control, the effect of such control on the emissions of these toxic compounds should be quite small.

References (Chapter 5)

1. "Evaporative HC Emissions for MOBILE3," Test and Evaluation Branch, U.S. EPA, EPA-AA-TEB-85-1, August 1984.

2. Data submitted in a formal letter from J.S. Welstand, Chevron Research Division, to Chester J. France, EPA, OMS, ECTD, April 1, 1985.

3. "Relationship Between Exhaust Emissions and Fuel Volatility," EPA memo from Thomas L. Darlington to Charles L. Gray, EPA, OMS, ECTD, June 24, 1985.

4. "Compilation of Air Pollution Emission Factors: Highway Mobile Sources," U.S. EPA, EPA-460/3-81-005, March 1981.

5. "Refueling Emissions from Uncontrolled Vehicles," Dale S. Rothman and Robert Johnson, OMS, ECTD, EPA-AA-SDSB-85-6, July 1985.

6. "Bulk Plants -- Control of Volatile Organic Emissions from Bulk Gasoline Plants (CTG)," U.S. EPA, OAQPS, EPA-450/2-77-035, December 1977.

7. "Service Stations -- Design Criteria for Stage I Vapor Control Systems -- Gasoline Service Stations (CTG)," U.S. EPA, OAQPS, EPA Internal Document, November 1975.

8. "Gasoline Tank Trucks -- Control of Volatile Organic Compound Leaks from Gasoline Tank Trucks and Vapor Collection Systems (CTG)," U.S. EPA, OAQPS, EPA-450/2-78-051, December 1978.

9. "Fixed-Roof Tanks -- Control of Volatile Organic Emissions from Storage of Petroleum Liquids in Fixed-Roof Tanks (CTG)," U.S. EPA, OAQPS, EPA-450/2-77-036, December 1977.

10. "Floating-Roof Tanks -- Control of Volatile Organic Emissions from Petroleum Liquid Storage in External Floating-Roof Tanks (CTG)," U.S. EPA, OAQPS, EPA-450/2-78-047, December 1978.

11. "Bulk Terminals -- Control of Hydrocarbons from Tank Truck Gasoline Loading Terminals (CTG)," U.S. EPA, OAQPS, EPA-450/2-77-026, October 1977.

References (Chapter 5) Cont'd

12. "Methodology to Conduct Air Quality Assessments of National Mobile Source Emission Control Strategies; Final Report," U.S. EPA, OAQPS, EPA-450/4-80-026, October 1980.

13. Computerized data files in support of "National Air Pollutant Emissions Estimates, 1940-1983," U.S. EPA, OAQPS, MDAD, EPA-450/4-84-028, December 1984.

14. "Updated Trips- and Miles-per-Day Information," EPA Memo from Thomas Darlington, Test and Evaluation Branch, to Charles L. Gray, Director of Emission Control Technology Division, January 30, 1985.

15. "1981-1983 Standard Metropolitan Statistical Area (SMSA) Air Quality Data Base for Use in Regulatory Analysis," Memo from Richard G. Rhoads, Director of Monitoring and Data Analysis Division, to Charles L. Gray, Director of Emission Control Technology Division, February 25, 1985.

16. "Uses, Limitations and Technical Basis of Procedures for Quantifying Relationships Between Photochemical Oxidants and Precursors," U.S. EPA, OAQPS, RTP, EPA-450/2-77-021a, November 1977.

17. "Guidelines for Use of City-Specific EKMA in Preparing Ozone SIPs," U.S. EPA, OAQPS, RTP, EPA-450/4-80-027, March 1981.

18. "Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry," U.S. EPA, OAQPS, EPA-450/3-84-012a, July 1984.

19. "Motor Gasolines, Summer 1984," Ella Mae Shelton and Cheryl L. Dickson, National Institute for Petroleum and Energy Research (NIPER), for API, February 1985.

20. "Composition of Automobile Evaporative and Tailpipe Hydrocarbon Emissions," F.M. Black and L.E. High, U.S. EPA, J.M. Lang, Northrop Services, Inc., APCA Journal, Vol. 30, No. 11, November 1980.

21. "MOBILE3 Fuel Consumption Model," Mark A. Wolcott, EPA, and Dennis F. Kahlbaum, CSC, February 1985.

22. "Transmittal of Emissions Inventory and RVP Data," EPA memo from Glenn W. Passavant, EPA to Jeff Clark, General Accounting Office, March 22, 1985.

23. "GAO Request for Background Information on Benzene," EPA memo from Robert G. Kellam, EPA to Joseph L. Turlington, General Accounting Office, May 21, 1985.

CHAPTER 6

Analysis of Alternatives

I. Introduction

This final chapter draws on the findings presented earlier in the report and provides a direct comparison of the various HC control strategies being examined. This comparison is based on the estimated costs of motor vehicle-related controls and in-use fuel controls (presented, respectively, in Chapters 3 and 4) and on projected emissions benefits (discussed in Chapter 5) associated with each of the long- and short-term control scenarios. Using this information, cost effectiveness ($/ton) figures were developed as a basis for evaluating appropriate control measures. The emission reductions associated with each control scenario, along with their relative cost effectiveness, will be the focus of this chapter.

Both long-term control strategies, where in-use RVP and certification fuel RVP are made equal, and short-term control strategies, where in-use fuel is temporarily controlled to a lower RVP level than certification fuel, will be examined in terms of cost, emission reductions, and resulting cost effectiveness. The long-term analysis will focus on the year 2010 as a "steady-state" point at which essentially the entire motor vehicle fleet will have turned over (i.e., revised certification fuel and test procedure will have affected the design of almost all of the vehicles in the field). The short-term discussion will examine the years 1988, 1990, 1992, 1995, 1997, and 2000, and will focus on benefits achievable with additional in-use RVP control over and above those benefits resulting from the long-term strategies (i.e., certification RVP equal to in-use RVP).

As discussed earlier in Chapter 2, ozone-related HC control appears to be most valuable during the summer months, as over 90 percent of all ozone violations tend to occur between June and September (inclusive). Because of this, both 12-month (year-round) and 4-month (summer only) analyses will be performed below.* In both cases, the period of analysis represents both the control period for in-use volatility control and the period of consideration of emission benefits.

---

* Summer periods other than four months could also have been evaluated. Cost-per-ton estimates for 3-, 5-, or 6-month control periods could be determined in a fairly linear fashion. For example, 6-month benefits would be one-half of annual tons, costs would be roughly three-quarters of annual dollars, so cost per ton would be approximately 1.5 times higher than the annual figure.

Due to the uncertainty associated with the relative value of ozone benefits in the summer and winter, the discussion of the results in this chapter will focus primarily on the 12-month figures.

Section II below outlines the methodologies and assumptions used to calculate cost effectiveness estimates for both the long- and short-term control strategies. (The discussions on the development of costs and emissions reductions are merely reviews, as the details on both are presented in Chapters 3 through 5.) Following the methodology descriptions, Section III presents the results of the analyses, first for the long-term and then for the short-term strategies.

An analysis of alternatives based on best estimates and current conditions will be presented first. This "base" case includes no control of vehicle refueling losses and no inspection and maintenance (I/M) programs for evaporative emissions, as these have not been implemented to date. As discussed in Chapter 4, the ratio of percentage change in fuel economy to percentage change in fuel energy content (due to butane removal), designated "R", should theoretically be 1.00. However, limited available data indicate a lower boundary of 0.6 for this ratio. Therefore, base case costs and credits are evaluated for both R = 1.0 and R = 0.6, but a 100-percent efficiency still represents the best estimate at this time, as the theory is sound (see Chapter 4).

In addition to the base case analysis, Section III will also present the results of various sensitivity analyses. The first sensitivity analysis will examine the effect of average in-use gasoline RVP staying fairly constant at the current 0.5 psi (on average) below ASTM limits rather than reaching these limits (e.g., average Class C RVP would stay at 11.0 psi, instead of reaching the baseline value of 11.5 psi by 1988). Because RVPs are not expected to decrease below current levels without further regulation, this sensitivity analysis represents a worst-case impact on the RVP control scenarios. As with the base case, this sensitivity analysis is performed for both R = 1.0 and R = 0.6.

The second sensitivity analysis will examine the effect of implementing onboard vehicle refueling loss controls in 1989, an issue now under study within EPA. If onboard controls are required, that rulemaking could include a revision of certification fuel RVP to 11.5 psi and a change in the evaporative test procedure to require a saturated canister at the start of the certification test. However, the revisions to the test fuel and evaporative test procedure could be made without implementing onboard refueling controls. Thus these revisions and their resulting emission reductions should not be unequivocally associated with onboard refueling controls. On the increment, when considering both RVP and refueling controls, it seems most proper to associate the control of excess evaporative and exhaust HC emissions due to high in-use RVP to RVP control (vehicle or in-use fuel) and to associate the control of refueling emissions with onboard refueling controls. Thus, the majority of the refueling emission control previously associated with in-use RVP control must be subtracted out for the onboard sensitivity analysis; a very small amount of refueling loss control is still achievable with RVP control due to tampering with onboard systems. (More detail is given in Section II.) As before, this sensitivity analysis is performed at both "R" values -- 1.0 and 0.6.

The third sensitivity analysis will examine the effect of eliminating the exhaust HC emission reductions associated with RVP control. As discussed in Chapter 2, in-use EF test data indicate that exhaust emissions decrease with lower RVPs. While there is no reason to question these technical results, a sensitivity analysis without these RVP-related exhaust HC reductions has been performed to examine the significance of these exhaust benefits with respect to the base case costs/ton. This case is evaluated with an "R" value of 1.0 only.

The fourth sensitivity analysis will examine the effect of implementing an inspection and maintenance program for evaporative control systems. By identifying and theoretically preventing vehicle problems, this type of program would reduce tampering and malmaintenance/defect losses, which are now only affected by in-use RVP control. To date, I/M programs have been implemented only for exhaust emission control equipment, so only exhaust I/M was included in the base case. A sensitivity analysis with an evaporative I/M program was performed because of the possibility of such a program coming into place in the late 1980's. As with the "no exhaust benefits" case, only R = 1.0 was evaluated.

II. Methodology

A. Long-Term Analysis

The methodology used to estimate the long-term (steady-state) costs, emission reductions, and resulting cost effectiveness of controlling evaporative HC emissions through equating in-use and certification gasoline RVPs along with revisions to certification test procedure is detailed in this section. The methodology for the year-round (12-month) analysis will be presented first, followed by that of summer-only (4-month) analyses. The year 2010 was used to represent the long term, as the vehicle fleet would consist entirely of post-1990 (i.e., controlled) vehicles by this time.

Estimation of the 2010 non-California emission reductions associated with the base case (including exhaust HC benefits, without onboard refueling loss control and with no evaporative I/M program) were simply taken from total inventory projections of the previous chapter (see Table 5-12). Net and incremental emission reductions were estimated for each long-term control scenario (11.5-psi RVP down to 9.0-psi RVP in 0.5-psi increments).* The sources of NMHC emission reductions include motor vehicle evaporative and exhaust emissions, and gasoline storage and distribution sources (i.e., bulk storage, Stage I, and refueling).

The emission reductions estimated for the long-term control scenarios are presented in Table 6-1 for the base case and the four sensitivity analyses. Emission reductions are detailed here in order to provide a perspective on the relative contribution of various sources -- motor vehicle evaporative losses, motor vehicle exhaust emissions, refueling, bulk storage, and Stage I. As shown, motor vehicle evaporative emissions make up the largest controlled category, accounting for 61 to 63 percent of total NMHC reductions in 2010 (assuming the base case).

Estimation of the emission reductions associated with the various sensitivity analyses vary in complexity. Elimination of the RVP-related exhaust emission effect simply involves removing the portion of the emission reduction attributable to motor vehicle exhaust emission control (i.e., 215,000 tons in 2010) shown in Table 6-1. For the "lower baseline RVP" case, emission reductions are simply calculated from a new baseline -- in-use RVP = 11.0 psi and certification fuel RVP = 9.0 psi -- instead of the 11.5/9.0 RVP baseline used in the base case. In other words, in Table 6-1, emission reductions for this sensitivity case are 262,000 tons lower than base case reductions under all RVP scenarios, which represents the difference between the 11.5/9.0 and the 11.0/9.0 baseline inventories.

Consideration of the presence of onboard refueling loss controls is only slightly more complex. Since in-use RVP control affects even controlled refueling losses (by the same proportion as uncontrolled emissions) and onboard controls would be subject to some degree of tampering, some control of refueling loss persists even if onboard controls are implemented. Based on previous EPA studies, onboard controls are at least 97 percent effective; accounting for the projected tampering incidence (the same as the then-current evaporative control tampering rate), refueling emissions are expected to be

---

* The uncontrolled baseline assumes an in-use fuel RVP of 11.5 psi and a certification fuel RVP of 9.0 psi.

Table 6-1

Annual Emission Reductions Under
Long-Term Control Scenarios in 2010 (10^3 Tons)*

	In-Use = Cert. RVP (psi)					
Case/Category	11.5	11.0	10.5	10.0	9.5	9.0
"Base Case":						
- Evap.HC	369	419	468	516	564	613
- Exhaust HC	215	215	215	215	215	215
- Refueling	0	17	34	51	68	85
- Bulk Storage	0	12	25	38	51	64
- Stage I	0	6	13	20	27	33
- Total	584	669	755	840	925	1010
"Lower Baseline" Case:**						
- Evap. HC	-	230	279	327	375	424
- Exhaust HC	-	177	177	177	177	177
- Refueling	-	0	17	34	51	68
- Bulk Storage	-	0	13	26	39	52
- Stage I	-	0	7	14	21	27
- Total	-	407	493	578	663	748
"Onboard" Case:						
- Evap. HC	369	419	468	516	564	613
- Exhaust HC	215	215	215	215	215	215
- Refueling	0	1	2	3	4	5
- Bulk Storage	0	12	25	38	51	64
- Stage I	0	6	13	20	27	33
- Total	584	653	723	792	861	930
"No Exhaust" Case:						
- Evap. HC	369	419	468	516	564	613
- Exhaust HC	0	0	0	0	0	0
- Refueling	0	17	34	51	68	85
- Bulk Storage	0	12	25	38	51	64
- Stage I	0	6	13	20	27	33
- Total	369	454	540	625	710	795
"Evap. I/M" Case:						
- Evap. HC	284	305	324	344	361	378
- Exhaust HC	215	215	215	215	215	215
- Refueling	0	17	34	51	68	85
- Bulk Storage	0	12	25	38	51	64
- Stage I	0	6	13	20	27	33
- Total	499	555	611	668	722	775

---

* Non-California emission reductions only.

** Assumes baseline in-use RVP of 11.0 psi, instead of 11.5 psi.

controlled by 94 percent in 2010 (i.e., essentially all models in the fleet will be equipped with onboard controls).[1] Thus, the 2010 emission reductions attributable to refueling loss control are reduced by 94 percent, as indicated in Table 6-1. As mentioned earlier, implementation of an onboard refueling loss control program could also involve a revision of the certification fuel RVP specification to 11.5 psi and a change in evaporative test procedure (i.e., beginning with a saturated canister). However, as mentioned before, these test procedure revisions could be implemented without implementing onboard refueling controls and, therefore, should not be inherently associated with onboard refueling controls. Thus, the emission reductions associated with changing the RVP of the test fuel and the evaporative test procedure (the control of vehicle evaporative and exhaust HC emissions at 11.5 psi RVP) will be retained for this onboard sensitivity analysis. The 94-percent reduction in refueling loss control due to implementation of an onboard program reduces the overall effect of RVP control by up to 8 percent in comparison to the base case.

Consideration of the presence of an effective inspection and maintenance (I/M) program for evaporative control systems is also somewhat complex. Evaporative I/M programs could affect both the malmaintenance and defect effect and the tampering effect associated with motor vehicle evaporative emissions. In Chapter 2 of this study, specific vehicle problems were classified as malmaintenance/defect or tampering (see Table 2-14). By detecting and forcing repair of such problems as a broken canister or damaged vacuum line (malmaintenance/defect) or a missing canister or fuel cap (tampering), an evaporative I/M program could reduce portions of these excess evaporative emissions. It was assumed that such a program could potentially address all types of tampering, but only certain types of malmaintenance and defects. (Appendix 6-A contains the analysis of the potential for I/M to address the various specific types of malmaintenance and defects). An evaporative I/M program was assumed to be 70 percent effective in eliminating both tampering and applicable malmaintenance and defects.[3] The estimated maximum portions of hot-soak and diurnal emissions from carbureted and fuel-injected vehicles that would potentially be affected by I/M are shown in Table 6-2. The resulting 2010 motor vehicle evaporative emission reductions associated with RVP control in conjunction with an evaporative I/M program are shown in Table 6-1. In order to compare this case with the other sensitivity cases shown in the table, a nationwide analysis (excluding California) was performed, even though an evaporative I/M program would most likely be implemented only in urban ozone non-attainment areas. However, the relative impact of such a program on emissions in just these urban areas would parallel that indicated in the nationwide analysis. As shown in Table 6-1, overall emission reductions due to RVP control are 14-23 percent lower under this evaporative I/M sensitivity case than for the base case.

Table 6-2

Effect of Evaporative I/M on Malmaintenance/Defect Effect and Tampering Rates for 1981+ Model Years (Baseline Case)

	M&D Emission Rates (LDV & LDT)			
	FI		Carb.	
	DI	HS	DI	HS
w/o Evaporative I/M (g/test)	.84	.93	1.61	1.24
w/ Evaporative I/M (g/test)*	.39	.34	1.02	.84
% reduction in M&D	54.0	63.7	36.6	32.0

	Tampering Rates (%)					
	LDV Mileage			LDT Mileage		
	0	50K	100K	0	50K	100K
w/o Evaporative I/M	0	3.9	7.8	3.6	7.6	11.6
w/ Evaporative I/M*	0	1.2	2.3	1.1	2.3	3.5

---

* Assumes an evaporative I/M program efficiency of 70% (i.e., 70% of tampering is caught, and 70% of each addressable M&D problem is caught).

Moving to the estimation of costs, the net cost of commercial gasoline and motor vehicle-related controls are a function of several individual components. These include: 1) the refinery cost of reducing gasoline RVP, 2) the cost of motor vehicle redesign, 3) the value of the increased energy content of commercial gasoline, 4) the value of recovered or prevented evaporative HC losses, and 5) the cost of increased vehicle weight due to the enlarged canister. The combination of these individual components is described below. The detailed derivation of the individual vehicle- and fuel-related control costs are provided in Chapters 3 and 4, respectively. The only exception is the evaluation of the weight-related fuel economy penalty, which is described in Appendix 6-B at the end of this chapter. Like emission reductions, all costs are determined on an annual basis.

The refinery costs of reducing RVP are taken from Table 4-3 of Chapter 4. For this 2010 scenario, the "with investment" costs are most applicable and, as described in Chapter 4, the average of the "open" and "fixed" NGL cases was used. Nationwide (non-California) annual costs are simply calculated by multiplying these refinery costs by nationwide gasoline consumption (excluding California and off-highway gasoline consumption) from EPA's MOBILE3 Fuel Consumption Model (FCM) for the year 2010.[4] This annual consumption is 75 billion gallons (1.79 million barrels). These refinery costs are summarized in Table 6-3 and do not vary with any of the sensitivity cases except where the RVP of commercial gasoline only rises to 11 psi. In this case, the cost of the first 0.5 psi of RVP control is avoided.

The costs of vehicle redesign, on a dollar-per-vehicle basis, are taken from Table 3-6 in Chapter 3. These are multiplied by Energy and Environmental Analysis (EEA) vehicle sales projections for the year 2010 to determine annual costs.[5] The resulting annual vehicle design costs are summarized in Table 6-3 and do not vary with sensitivity case.

Reducing in-use gasoline RVP also increases the energy density of the gasoline, which, in turn, results in increased fuel economy in motor vehicles. The effects are summarized in Table 4-11 of Chapter 4. The annual credit is estimated by multiplying the increases in vehicular fuel economy of Table 4-11 by the non-California nationwide fuel consumption described above and an estimated value of gasoline of $0.98 per gallon. The resulting credits are shown in Table 6-3 for both the base case, where R (the fraction of the increased energy that is fully utilized by the engine) equals 1.0, and for the sensitivity case assuming an R-value of 0.6. The credit for the latter is simply 60 percent of the former.

Table 6-3

Annual Costs Under Long-Term Control Scenarios in 2010 (10^6\$/yr)

Case/Category	In-Use = Cert. RVP (psi)					
	11.5	11.0	10.5	10.0	9.5	9.0
"Base Case":						
- Refinery Cost	0	192	421	686	962	1256
- Vehicle Cost	28	23	18	14	9	0
- Fuel Econ. Credit*	0	- 72	-163	-261	-366	-477
- Evap. Recov. Credit	-196	-224	-254	-283	-311	-339
- Weight Penalty	8	7	5	3	2	0
- Total Cost	-160	- 75	28	159	296	440
"Lower Baseline" Case:**						
- Refinery Cost	N.A.***	0	229	494	770	1064
- Vehicle Cost	N.A.	23	18	14	9	0
- Fuel Econ. Credit*	N.A.	0	- 91	-189	-294	-405
- Evap. Recov. Credit	N.A.	-137	-165	-194	-222	-251
- Weight Penalty	N.A.	7	5	3	2	0
- Total Cost	N.A.	-107	- 4	128	264	408
"Onboard" Case:						
- Refinery Cost	0	192	421	686	962	1256
- Vehicle Cost	28	23	18	14	9	0
- Fuel Econ. Credit*	0	- 72	-163	-261	-366	-477
- Evap. Recov. Credit	-196	-219	-243	-267	-289	-312
- Weight Penalty	8	7	5	3	2	0
- Total Cost	-160	- 69	38	175	318	467
"No Exhaust" Case:						
- Refinery Cost	0	192	421	686	962	1256
- Vehicle Cost	28	23	18	14	9	0
- Fuel Econ. Credit*	0	- 72	-163	-261	-366	-477
- Evap. Recov. Credit	-124	-152	-181	-210	-238	-267
- Weight Penalty	8	7	5	3	2	0
- Total Cost	- 88	2	100	232	368	512
"Evap. I/M" Case:						
- Refinery Cost	0	192	421	686	962	1256
- Vehicle Cost	28	23	18	14	9	0
- Fuel Econ. Credit*	0	- 72	-163	-261	-366	-477
- Evap. Recov. Credit	-166	-186	-205	-224	-242	-266
- Weight Penalty	8	7	5	3	2	0
- Total Cost	-130	- 36	76	218	365	513

---

* For R = 1.0; when R = 0.6, fuel economy credit is reduced by 40%.

** Assumes baseline in-use RVP of 11.0 psi, instead of 11.5 psi.

*** Not Applicable.

The methodology for valuing recovered/prevented evaporative HCs from the gasoline storage and distribution system, vehicle refueling, and motor vehicle operation was derived in Section VI of Chapter 4. There, the value of HC (butane) control was determined to be $335.26 per ton. The overall emission reductions shown in Table 6-1 for the various cases can simply be multiplied by this value to derive the annual recovery credits. These are shown in Table 6-3.

As alluded to in Chapter 3, redesigning motor vehicles for higher volatility would increase the weight of the motor vehicle slightly, as a larger canister would be required. This weight increase would cause the motor vehicle to consume more fuel over the course of its lifetime than if the vehicle did not have added weight due to redesign. This weight penalty and associated discounted lifetime costs per vehicle are derived in Appendix 6-B at the end of this chapter and are summarized in Table 6-B-2. These per-vehicle costs are multiplied by the sales projections described earlier to derive annual costs, which are summarized in Table 6-3.

The net costs for each control scenario are then calculated by simply adding costs and subtracting credits. The long-term, steady-state cost effectiveness is determined by simply dividing net annual cost by annual emission reduction.

The calculations for the 4-month analysis are very similar to those for the 12-month period. Again, the 4-month analysis assumes commercial (in-use) fuel RVP control is implemented only during a 4-month summer period. Of course, as certification fuel changes affect vehicle design, year-round HC control is inherently provided and, thus, no option for seasonal control is available with that approach.

Based on the above assumptions, emission reductions for a 4-month summer period (shown in Table 6-4) are simply one-third of those developed for the 12-month analysis. Any emission reductions due to vehicle-related control during the non-summer period are ignored.

The cost calculations, however, must take into account the fact that vehicle-related costs and credits occur year-round, even though any commercial fuel volatility controls are removed. Thus, 4-month refinery costs and credits due to increased fuel density are simply one-third of the year-round values. Vehicle redesign costs and the associated weight penalty are the same as the year-round values, since all vehicles must be modified in any case. However, derivation of the evaporative recovery/prevention credit is more complex. During the summer period, this credit is simply one-third of the year-round figure since both fuel- and vehicle-related controls are fully operable. However, some additional emission

Table 6-4

4-Month Emission Reductions Under Long-Term Control Scenarios in 2010 (10^3 Tons)*

	In-Use = Cert. RVP (psi)					
Case/Category	11.5	11.0	10.5	10.0	9.5	9.0
"Base Case":						
- Evap. HC	123	139	157	171	187	205
- Exhaust HC	72	72	72	72	72	72
- Refueling	0	6	11	17	23	28
- Bulk Storage	0	4	8	13	17	21
- Stage I	0	2	4	7	9	11
- Total	195	223	252	280	308	337
"Lower Baseline" Case:**						
- Evap. HC	-	77	95	109	125	143
- Exhaust HC	-	59	59	59	59	59
- Refueling	-	0	5	11	17	22
- Bulk Storage	-	0	4	9	13	17
- Stage I	-	0	2	5	7	9
- Total	-	136	165	193	221	250
"Onboard" Case:						
- Evap. HC	123	139	157	171	187	205
- Exhaust HC	72	72	72	72	72	72
- Refueling	0	0	1	1	1	2
- Bulk Storage	0	4	8	13	17	21
- Stage I	0	2	4	7	9	11
- Total	195	217	242	264	286	311
"No Exhaust" Case:						
- Evap. HC	123	139	157	171	187	205
- Exhaust HC	0	0	0	0	0	0
- Refueling	0	6	11	17	23	28
- Bulk Storage	0	4	8	13	17	21
- Stage I	0	2	4	7	9	11
- Total	123	151	180	208	236	265
"Evap. I/M" Case:						
- Evap. HC	94	101	109	114	120	126
- Exhaust HC	72	72	72	72	72	72
- Refueling	0	6	11	17	23	28
- Bulk Storage	0	4	8	13	17	21
- Stage I	0	2	4	7	9	11
- Total	166	185	204	223	241	258

---

* Non-California emission reductions only.

** Assumes baseline in-use RVP of 11.0 psi, instead of 11.5 psi.

control occurs in the non-summer period in all scenarios where vehicle redesign is required (i.e., except for the 9.0-psi RVP case, where no change is made to certification fuel volatility). These non-summer emission reductions were estimated by running MOBILE3 (described in Chapter 5) to simulate a commercial fuel RVP of 11.5 psi with certification volatilities varying between 9.5 and 11.5 psi RVP. The development of these non-summer credits for the 4-month analysis is described in Appendix 6-C. The resulting summer and non-summer credits, as well as all the other 4-month costs and credits, are summarized in Table 6-5.

The cost effectiveness for summer-only emission reductions is again calculated by dividing the net 4-month cost by the 4-month emission reductions. All cost effectiveness estimates (both 12-month and 4-month) will be presented in Section III in Tables 6-6 through 6-21 and shown graphically in Figures 6-1 through 6-8. Their relative significance will be analyzed and interpreted as the estimates are presented.

B. Short-Term Analysis

As alluded to throughout this study, ozone control is the primary focus of the various HC reduction strategies being evaluated. Any reductions achievable in the shorter term could be important in view of the Clean Air act requirement that all urban areas be in attainment of the ozone NAAQS by 1987. Although the long-term strategy is to ensure that certification fuel RVP is representative of in-use levels, a short-term strategy could be to control in-use fuel RVP to a level lower than the long-term specification in order to achieve the additional benefits associated only with in-use RVP control. These benefits include: 1) an immediate effect on the entire motor vehicle fleet, including older vehicles not affected by the revised certification fuel, and 2) further control of in-use RVP-related emissions such as gasoline storage, distribution, refueling, and vehicular emissions due to tampering, malmaintenance and defects.

Therefore, a short-term analysis has been performed to focus on the incremental costs and emission reductions of additional in-use RVP control over and above the long-term RVP control strategies. This analysis focuses on the years 1988, 1990, 1992, 1995, 1997 and 2000. As before, the 12-month analysis is described first, followed by the 4-month analysis.

Year-round non-California HC emission inventories with additional short-term in-use RVP control were estimated in Chapter 5 and summarized in Table 5-14; emission reductions were calculated from this table and used directly for the base case here. Modification of these estimates for the various sensitivity cases is handled in exactly the same manner as described for the long-term analysis. As these emission reductions are due solely to in-use RVP control, the emission reductions for the 4-month analysis are simply one-third of the year-round reductions.

Table 6-5

4-Month Costs Under Long-Term Control Scenarios in 2010 (10^6\$/yr)

Case/Category	In-Use = Cert. RVP (psi) 11.5	11.0	10.5	10.0	9.5	9.0
"Base Case":						
- Refinery Cost	0	64	140	229	321	419
- Vehicle Cost	28	23	18	14	9	0
- Fuel Econ. Credit*	0	-24	- 55	- 87	-122	-159
- Evap. Recov. Credit	-191	-196	-193	-184	-154	-112
- Weight Penalty	8	7	5	3	2	0
- Total Cost	-155	-126	- 85	- 25	56	148
"Lower Baseline" Case:**						
- Refinery Cost	N.A***	0	76	165	257	355
- Vehicle Cost	N.A.	23	18	14	9	0
- Fuel Econ. Credit*	N.A.	0	- 31	- 63	- 98	-135
- Evap. Recov. Credit	N.A.	-132	-131	-125	-113	- 82
- Weight Penalty	N.A.	7	5	3	2	0
- Total Cost	N.A.	-102	- 63	- 6	56	138
"Onboard" Case:						
- Refinery Cost	0	64	140	229	321	419
- Vehicle Cost	28	23	18	14	9	0
- Fuel Econ. Credit*	0	- 24	- 55	- 87	-122	-159
- Evap. Recov. Credit	-191	-194	-189	-179	-147	-103
- Weight Penalty	8	7	5	3	2	0
- Total Cost	-155	-124	- 81	- 20	63	157
"No Exhaust" Case:						
- Refinery Cost	0	64	140	229	321	419
- Vehicle Cost	28	23	18	14	9	0
- Fuel Econ. Credit*	0	- 24	- 55	- 87	-122	-159
- Evap. Recov. Credit	-119	-137	-146	-146	-127	- 87
- Weight Penalty	8	7	5	3	2	0
- Total Cost	- 83	- 67	- 38	12	82	172
"Evap. I/M" Case:						
- Refinery Cost	0	64	140	229	321	419
- Vehicle Cost	28	23	18	14	9	0
- Fuel Econ. Credit*	0	- 24	- 55	- 87	-122	-159
- Evap. Recov. Credit	-162	-152	-145	-131	- 97	- 85
- Weight Penalty	8	7	5	3	2	0
- Total Cost	-126	- 82	- 37	28	113	175

---

* For R = 1.0; when R = 0.6, fuel economy credit is reduced by 40%.

** Assumes baseline in-use RVP of 11.0 psi, instead of 11.5 psi.

*** Not Applicable.

The year-round costs of additional in-use RVP control consist of only three parts: 1) refinery costs, 2) credit due to increased fuel density, and 3) credit due to recovered/ prevented evaporative emissions. As before, the refinery cost of each 0.5 psi of RVP control was taken from Table 4-3. Here, however, the "no-investment" costs were used for 1988 and 1990, as there would not likely be time for refiners to invest in capital equipment for the most economic RVP control refinery processes. "With investment" costs were assumed to apply for later years as: 1) at least five years of leadtime should be available prior to 1992 and 2) the short-term control would be in place sufficiently long to justify capital investment (i.e., 5-10 years). These costs per barrel were again multiplied by on-highway, non-California fuel consumption projections from EPA's MOBILE3 Fuel Consumption Model.[4]

The density-related fuel economy credit for each 0.5 psi of additional RVP control is again taken from Table 4-11 and multiplied by non-California fuel consumption. The evaporative emission recovery/prevention credit is again obtained by multiplying the emission reductions calculated from Table 5-14 for additional in-use RVP control by the butane value of $335.26 per ton. Since, in this analysis of additional short-term in-use RVP control, all costs are related to fuel control and none to vehicle control, the 4-month seasonal control costs are simply one-third of the year-round costs.

The cost effectiveness estimates for both the 12-month and the 4-month analyses are simply net costs divided by emission reductions. These estimates of cost/ton will be summarized along with long-term estimates in Tables 6-6 through 6-21 and Figures 6-1 through 6-8 in the following section.

III. Results

Using the methodologies described in the previous section, 12-month and 4-month costs and emission reductions were determined for each of the long- and short-term RVP control scenarios. Using these results, cost effectiveness estimates (control costs per ton) were determined as a basis for comparison of the various alternatives. This section focuses on these cost effectiveness estimates for the base case and for each of the sensitivity cases (i.e., lower baseline RVP, onboard, no exhaust benefits, and evaporative I/M). The base case and the first two sensitivity cases are evaluated using "R" values of both 1.0 and 0.6; the other two cases assume R = 1.0 only. Results of the 12-month and 4-month analyses for each of the cases will be presented in tabular form and their relative significance will be discussed. The 12-month tables will be supplemented by figures showing emission reductions over time, with constant cost effectiveness lines superimposed.

A. "Base" Case

The base case represents the combination of the current regulatory situation and EPA's best technical estimates. As outlined earlier, this includes: 1) no onboard or Stage II control of refueling losses, 2) no evaporative I/M program, 3) full utilization of increased gasoline energy content and recovered/prevented evaporative emissions by vehicles (i.e., R = 1.0), and 4) an assumption that in-use RVP will continue to rise until ASTM limits are reached (i.e., Class C summertime RVP will equal 11.5 psi, on average, by 1988).

Twelve-month emission reductions, costs, and cost effectiveness estimates are shown for the base case in Table 6-6; year-round reductions and costs are assumed. Results of this 12-month analysis are also shown graphically in Figure 6-1. Emission reductions over time are shown for each RVP control scenario. Constant cost effectiveness lines (dashed) have been drawn to facilitate comparison of the various control options. For instance, a specific cost-per-ton line can be traced over time and across RVP control scenarios to indicate equivalent control approaches for each year.

The top portion of Table 6-6 presents the long-term (2010) analysis, where certification fuel and in-use fuel RVPs are made equal. The 11.5-psi scenario represents purely vehicle-oriented control as it only requires a change in certification fuel RVP (i.e., in-use RVP is expected to average 11.5 psi); the 9.0-psi case, on the other hand, requires primarily in-use fuel control, with improvements to the evaporative emission test procedure but no change in the certification fuel. All of the intermediate RVP scenarios combine the fuel-related and vehicle-oriented approaches. Table 6-6 shows that, by 2010, the vehicle-oriented approach (11.5-psi scenario) is significantly more cost-effective than the scenarios involving fuel control, and actually results in an overall savings (i.e., negative $/ton). This occurs because fuel economy credits from recovered evaporative emissions outweigh the costs of vehicle redesign. However, additional incremental emission control is achievable via more in-use fuel-oriented programs at increasing cost per ton.

The center and bottom portions of Table 6-6 summarize the short-term analysis, where the strategy is to control in-use fuel RVP to a level lower than the long-term certification specification; after a specified time, in-use fuel control would be relaxed to the long-term certification RVP level chosen via the long-term analysis. The short-term analysis focuses on years between 1988 and 2000 (inclusive). The first column in this portion of the table shows the increment between the long-term certification/in-use specifications and the short-term in-use RVP; 0.5-psi increments are shown (e.g., long-term RVP = 11.5, short-term in-use RVP lower at 11.0).

Table 6-6

"Base" Case: 12-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 \$/Yr)		Cost Effectiveness (\$/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	584	584	-160	-160	-274	-274
11.0	669	85	- 75	85	-112	998
10.5	755	86	28	102	37	1197
10.0	840	85	159	132	190	1542
9.5	925	85	296	137	320	1619
9.0	1010	85	440	144	435	1681

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	283	260	217	167	138	110
11.0-10.5	255	233	196	151	128	105
10.5-10.0	216	196	166	131	113	95
10.0- 9.5	193	174	151	123	107	94
9.5- 9.0	169	155	137	114	105	92

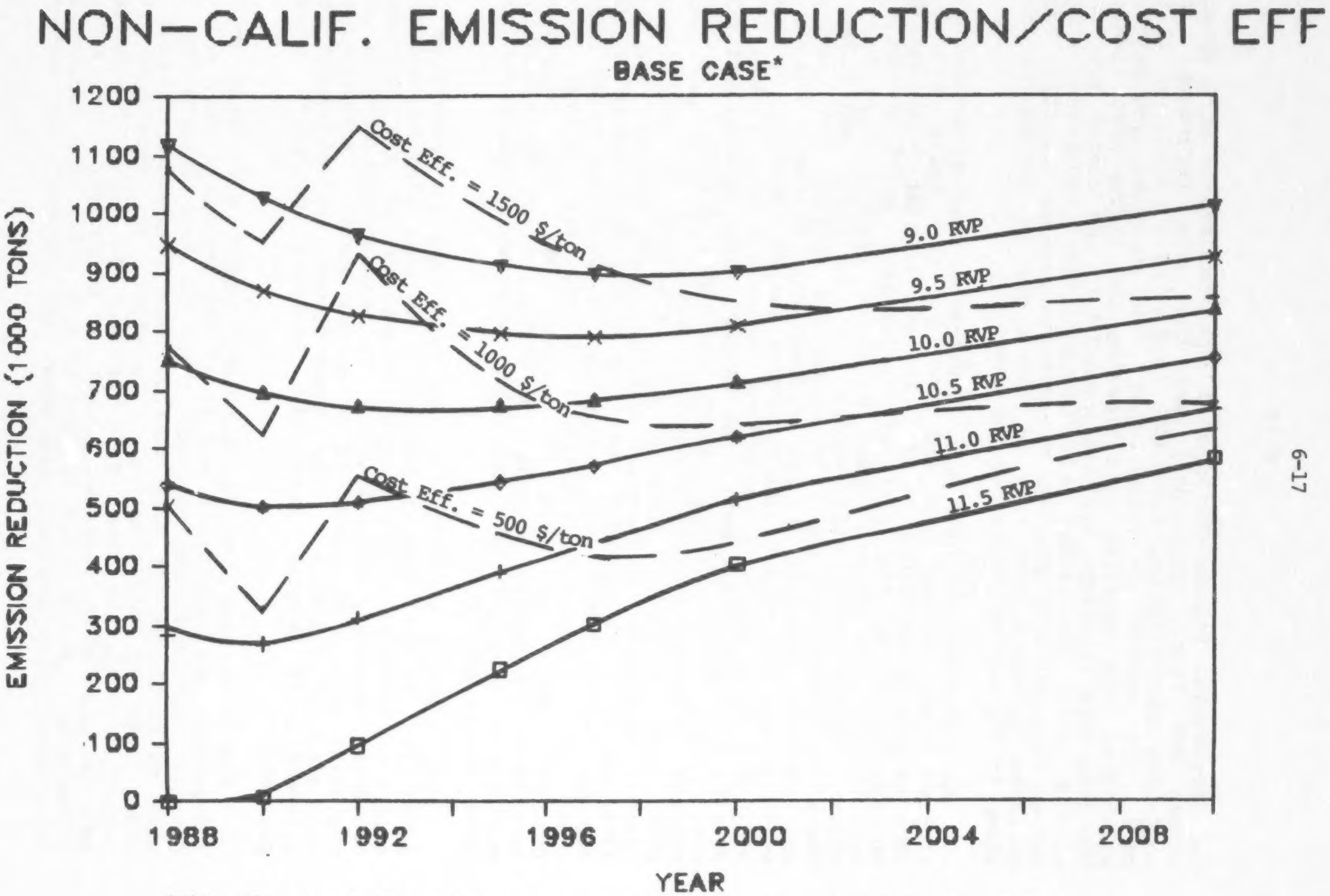
Incremental Control Step RVP (psi)	Incremental Cost Effectiveness (\$/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	395	438	239	382	586	697
11.0-10.5	598	685	425	607	840	972
10.5-10.0	1036	1101	670	883	1154	1262
10.0- 9.5	1200	1316	841	1053	1327	1389
9.5- 9.0	1551	1666	1046	1244	1490	1571

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Figure 6-1



NON-CALIF. EMISSION REDUCTION/COST EFF

BASE CASE*

*With exhaust emission effect, without onboard, no evaporative I/M, with R = 1.0.

The incremental values (based on 0.5-psi intervals) at a given in-use RVP (e.g., 10.0 psi) are the same regardless of long-term certification fuel RVP (e.g., 10.5, 11.0, or 11.5 psi). It should be noted that the emission reductions associated with equating certification and in-use RVPs (i.e., the long-term strategy) are not included in the center portion of the table, but rather only the additional reductions that can be obtained with short-term additional in-use control. The cost/ton estimates for each of these control increments are shown in the bottom portion of the table.

As indicated in Table 6-6, short-term cost effectiveness ($/ton) rises between 1988 and 1990, but then falls in 1992. This is easily explained -- the 1988 and 1990 analyses assume no investment on the part of refineries, while post-1990 calculations use control costs based on capital investments which improve the efficiencies of refinery operations. Therefore, later-year costs of in-use RVP control are reduced and resultant cost/ton in 1992 is lower than in 1990. However, while in-use RVP control costs remain rather constant between 1992 and 2000, emission reductions achievable with in-use RVP control decrease with time as the vehicle fleet gradually turns over (i.e., vehicles with larger canisters designed for the revised long-term certification RVP, beginning with the 1990 model year, start to make up more and more of the in-use fleet). Therefore, incremental cost/ton rises between 1992 and 2000 and tends to approach the long-term figures shown in the top portion of Table 6-6. Actually, if 2010 estimates were shown for short-term additional in-use RVP control, the cost/ton would be slightly higher than the long-term incremental estimates because the vehicle fleet would consist entirely of post-1990 vehicles which were overdesigned for the lower in-use RVP level.

The 4-month analysis for the base case is summarized in Table 6-7. As described in Section II of this chapter, 4-month emission reductions are simply one-third of the 12-month estimates; however, control costs are less straightforward and represent more than one-third of annual costs. Therefore, as indicated in Table 6-7, the 4-month cost effectiveness is arithmetically higher than the 12-month estimates shown previously.

The base case results discussed above are based on a 100-percent utilization (R = 1.0) of the increased fuel energy density. As mentioned earlier, there is some uncertainty in this estimate as the very limited data available indicate a wide range of efficiencies. Therefore, to determine the sensitivity of the base case results to this "R" value, calculations were repeated using a 60-percent utilization efficiency (i.e., R = 0.6 instead of R = 1.0). The results of this sensitivity analysis are shown for 12-month and 4-month

Table 6-7

"Base" Case: 4-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	195	195	-155	-155	- 799	- 799
11.0	223	28	-126	30	- 563	1045
10.5	252	29	- 85	41	- 336	1442
10.0	280	28	- 25	60	- 89	2092
9.5	308	28	56	81	182	2880
9.0	337	28	148	92	440	3229

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	94	87	72	55	46	37
11.0-10.5	85	78	65	50	43	35
10.5-10.0	72	65	55	44	38	32
10.0- 9.5	64	58	50	41	36	31
9.5- 9.0	56	52	46	38	35	30

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness ($/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	395	434	247	412	633	797
11.0-10.5	598	690	453	684	955	1170
10.5-10.0	1036	1104	728	1066	1404	1708
10.0- 9.5	1200	1323	972	1430	1866	2279
9.5- 9.0	1551	1683	1234	1756	2177	2732

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

control periods in Tables 6-8 and 6-9, respectively. Figure 6-2 presents the results of the 12-month analysis in the same manner as in Figure 6-1. As indicated in the tables, the lower R-value results in slightly higher costs (due to lower fuel economy credits) and, thus, arithmetically higher cost effectiveness. For example, in the 12-month analysis of the 9.0-psi long-term scenario, incremental cost/ton increases by 31 percent, or by $520/ton, with the lower R-value. However, as with the R = 1.0 case, net savings (negative $/ton) are still projected for the 11.5-psi and 11.0-psi long-term scenarios.

B. "Lower Baseline RVP" Case

The base case analyzed above assumes that, by 1988, average summer in-use RVPs will have reached the ASTM limits recommended for various areas (see Chapter 2, Section IV). This second sensitivity analysis examines the possibility that in-use RVP will not actually reach the ASTM limits by 1988, but will instead stay at current levels (i.e., roughly 0.5 psi below ASTM limits). Since our analysis focuses on Class C summertime RVPs, this changes the baseline in-use RVP of the study from 11.5 to 11.0 psi. (The baseline certification RVP is 9.0 psi in both cases.) Therefore, emission reductions from baseline are lower than under the base case discussed in Section A, as uncontrolled levels are lower (based on 11.0 psi instead of 11.5 psi). The sensitivity of lower baseline RVP was analyzed for both the 12-month and 4-month control cases. The results are summarized in Tables 6-10 and 6-11, respectively, for R equal to 1.0, and Tables 6-12 and 6-13, respectively, for R equal to 0.6. The 12-month results are also shown graphically for R = 1.0 and R = 0.6 in Figures 6-3 and 6-4, respectively.

As indicated by comparing these four tables with the previous four, a lower baseline RVP results in reduced net emission benefits and arithmetically higher net cost effectiveness. For example, with the 12-month long-term 9.0-psi case, net reductions are 26 percent lower and net costs are just slightly lower, which results in a 26-percent increase in overall cost/ton. However, as incremental cost/ton is the most relevant, it is important to note that in the 12-month analysis the incremental values below the new 11.0-psi RVP baseline remain essentially unchanged from the base case. In both cases, the 12-month long-term 9.0-psi scenario has an incremental cost/ton of almost $1700. The effect of the lower R value is the same as under the base case.

Table 6-8

"Base" Case: 12-Month Analysis, R = 0.6

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	584	584	-160	-160	-274	-274
11.0	669	85	- 46	114	- 69	1334
10.5	755	86	93	139	123	1625
10.0	840	85	264	171	314	2001
9.5	925	85	444	179	479	2114
9.0	1010	85	631	188	624	2201

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	283	260	217	167	138	110
11.0-10.5	255	233	196	151	128	105
10.5-10.0	216	196	166	131	113	95
10.0- 9.5	193	174	151	123	107	94
9.5- 9.0	169	155	137	114	105	92

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness ($/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	507	556	376	553	770	944
11.0-10.5	756	840	605	830	1074	1281
10.5-10.0	1235	1329	932	1201	1480	1679
10.0- 9.5	1437	1572	1128	1391	1668	1809
9.5- 9.0	1839	1972	1328	1628	1865	2035

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-9

"Base" Case: 4-Month Analysis, R = 0.6

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	195	195	-155	-155	- 799	- 799
11.0	223	28	-116	39	- 520	1382
10.5	252	29	- 63	53	- 250	1871
10.0	280	28	10	73	35	2551
9.5	308	28	105	95	340	3375
9.0	337	28	212	107	629	3749

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	94	87	72	55	46	37
11.0-10.5	85	78	65	50	43	35
10.5-10.0	72	65	55	44	38	32
10.0- 9.5	64	58	50	41	36	31
9.5- 9.0	56	52	46	38	35	30

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness ($/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	507	552	384	584	817	1044
11.0-10.5	756	845	633	907	1188	1479
10.5-10.0	1235	1332	990	1383	1729	2124
10.0- 9.5	1437	1578	1258	1768	2207	2699
9.5- 9.0	1839	1989	1570	2141	2553	3196

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Figure 6-2

NON-CALIF. EMISSION REDUCTION/COST EFF

BASE CASE WITH R = 0.6

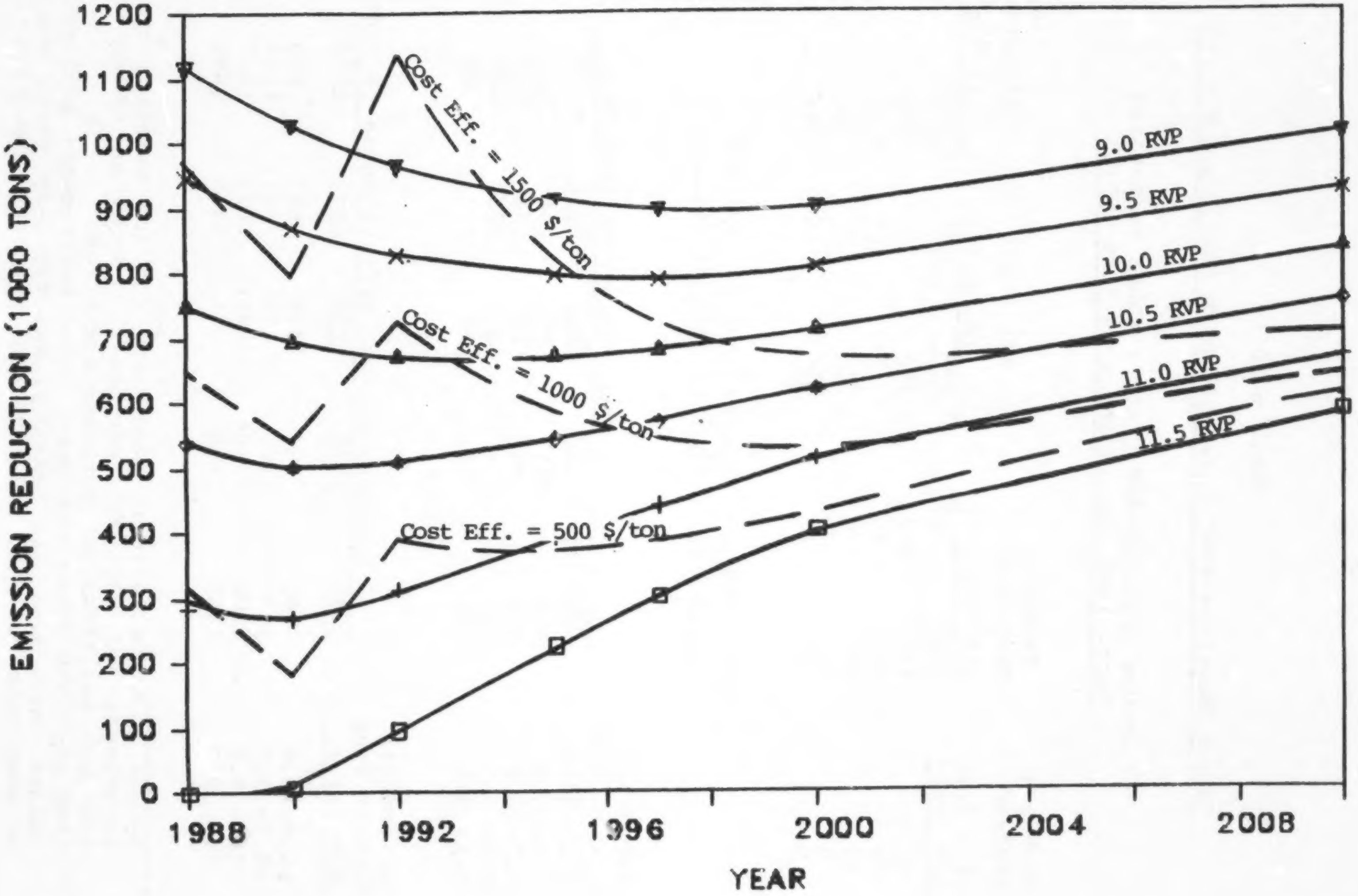


Table 6-10

"Lower Baseline RVP" Case: 12-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.0	407	407	-107	-107	-263	-263
10.5	493	86	- 4	103	- 8	1207
10.0	578	85	128	132	221	1541
9.5	663	85	264	136	399	1611
9.0	748	85	408	144	546	1685

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reduction (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.0-10.5	255	233	196	151	128	105
10.5-10.0	216	196	166	131	113	95
10.0- 9.5	193	174	151	123	107	94
9.5- 9.0	169	155	137	114	105	92

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness ($/Ton)**					
	1988	1990	1992	1995	1997	2000
11.0-10.5	598	685	425	607	840	972
10.5-10.0	1036	1101	670	883	1154	1262
10.0- 9.5	1200	1316	841	1053	1327	1389
9.5- 9.0	1551	1666	1046	1244	1490	1571

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-11

"Lower Baseline" Case: 4-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 \$/Yr)		Cost Effectiveness (\$/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.0	136	136	-102	-102	-755	-755
10.5	165	29	-63	39	-384	1379
10.0	193	28	-6	57	-32	1996
9.5	221	28	56	62	253	2204
9.0	249	28	138	82	552	2866

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reduction (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.0-10.5	85	78	65	50	43	35
10.5-10.0	72	65	55	44	38	32
10.0-9.5	64	58	50	41	36	31
9.5-9.0	56	52	46	38	35	30

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness (\$/Ton)**					
	1988	1990	1992	1995	1997	2000
11.0-10.5	598	690	453	684	955	1170
10.5-10.0	1036	1104	728	1066	1404	1708
10.0-9.5	1200	1323	972	1430	1866	2279
9.5-9.0	1551	1683	1234	1756	2177	2732

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-12

"Lower Baseline RVP" Case: 12-Month Analysis, R = 0.6

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.0	407	407	-107	-107	-263	-263
10.5	493	86	33	139	66	1633
10.0	578	85	204	171	352	2000
9.5	663	85	382	178	576	2108
9.0	748	85	570	188	763	2205

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reduction (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.0-10.5	255	233	196	151	128	105
10.5-10.0	216	196	166	131	113	95
10.0- 9.5	193	174	151	123	107	94
9.5- 9.0	169	155	137	114	105	92

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness ($/Ton)**					
	1988	1990	1992	1995	1997	2000
11.0-10.5	756	840	605	830	1074	1281
10.5-10.0	1235	1329	932	1201	1480	1679
10.0- 9.5	1437	1572	1128	1391	1668	1809
9.5- 9.0	1839	1972	1328	1628	1865	2035

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-13

"Lower Baseline" Case: 4-Month Analysis, R = 0.6

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr) Net	Emission Reductions (10^3 Tons/Yr) Incr.	Net Cost* (10^6 \$/Yr) Net	Net Cost* (10^6 \$/Yr) Incr.	Cost Effectiveness (\$/Ton) Net	Cost Effectiveness (\$/Ton) Incr.
11.0	136	136	-102	-102	-755	-755
10.5	165	29	-51	51	-310	1805
10.0	193	28	19	70	99	2455
9.5	221	28	95	76	431	2701
9.0	249	28	192	96	769	3386

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reduction (10^3 Tons) 1988	1990	1992	1995	1997	2000
11.0-11.5	85	78	65	50	43	35
10.5-10.0	72	65	55	44	38	32
10.0-9.5	64	58	50	41	36	31
9.5-9.0	56	52	46	38	35	30

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness (\$/Ton)** 1988	1990	1992	1995	1997	2000
11.0-10.0	756	845	633	907	1188	1479
10.5-10.0	1235	1332	990	1383	1729	2124
10.0-9.5	1437	1578	1258	1768	2207	2699
9.5-9.0	1839	1989	1570	2141	2553	3196

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Figure 6-3

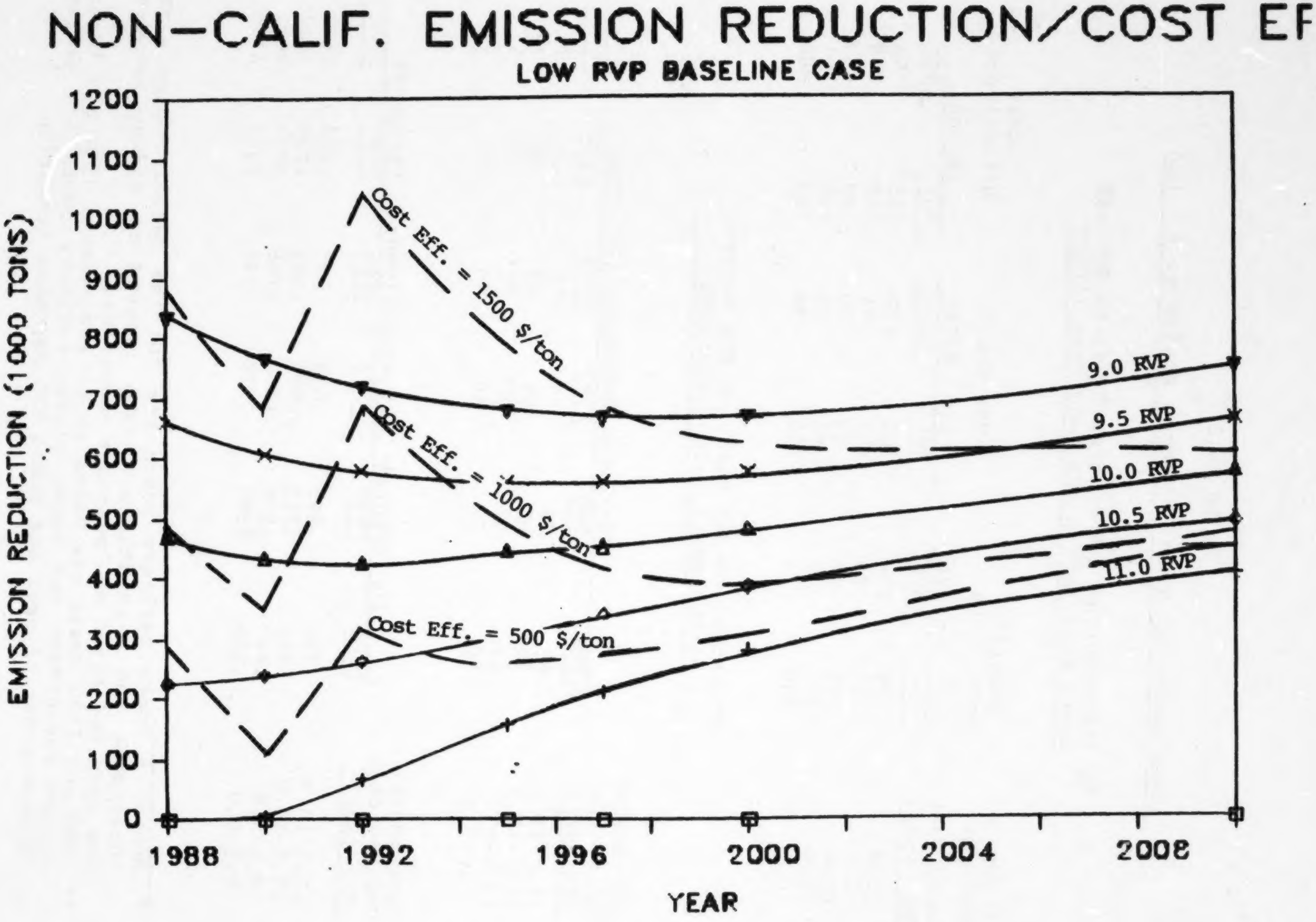
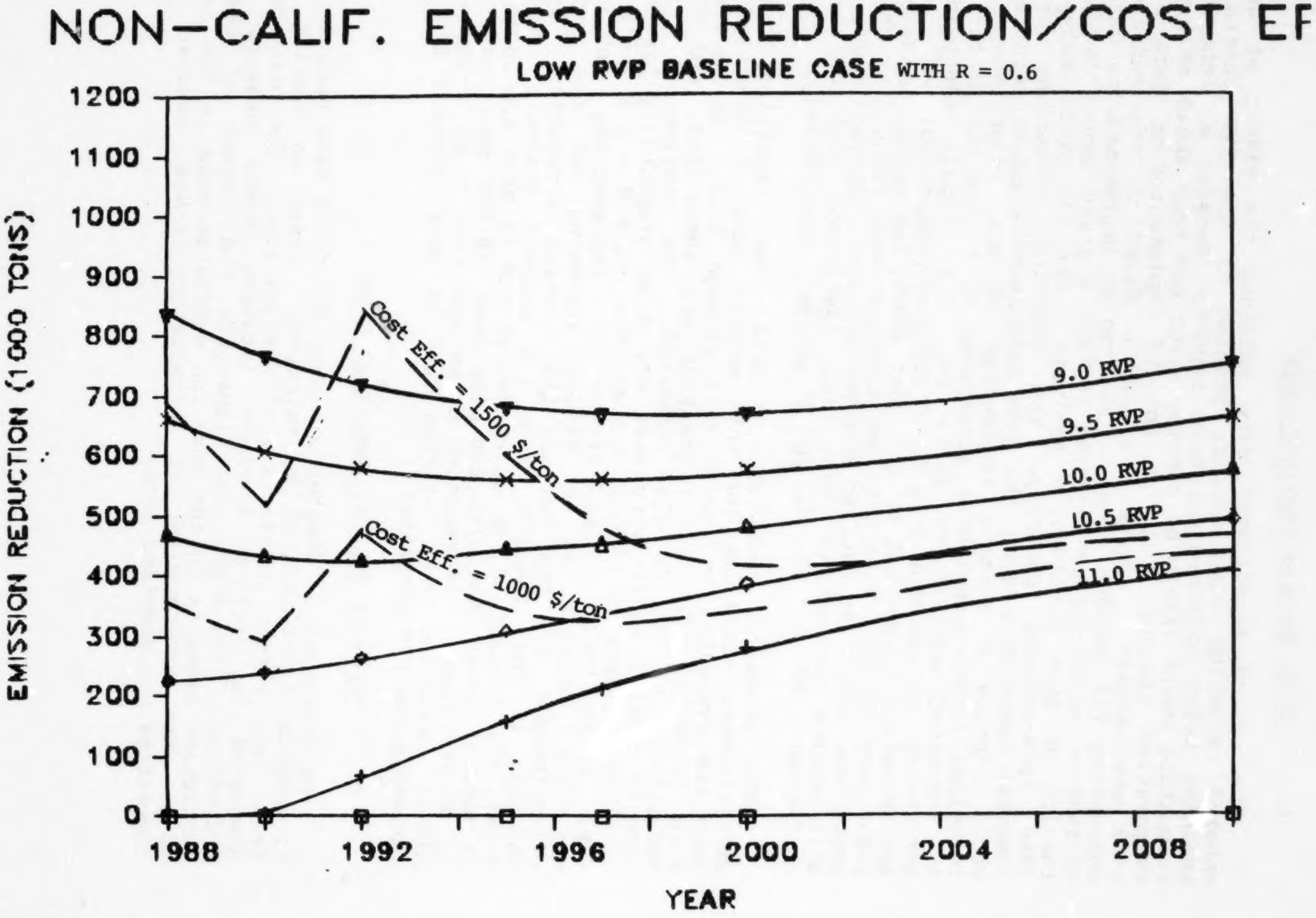

NON-CALIF. EMISSION REDUCTION/COST EF
LOW RVP BASELINE CASE
EMISSION REDUCTION (1000 TONS)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1988
1992
1996
2000
2004
2008
YEAR
Cost Eff. = 1500 $/ton
Cost Eff. = 1000 $/ton
Cost Eff. = 500 $/ton
9.0 RVP
9.5 RVP
10.0 RVP
10.5 RVP
11.0 RVP

Figure 6-4


NON-CALIF. EMISSION REDUCTION/COST EF
LOW RVP BASELINE CASE WITH R = 0.6
EMISSION REDUCTION (1000 TONS)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1988
1992
1996
2000
2004
2008
YEAR
9.0 RVP
9.5 RVP
10.0 RVP
10.5 RVP
11.0 RVP
Cost Eff. = 1500 $/ton
Cost Eff. = 1000 $/ton

C. "With Onboard Control" Case

The third sensitivity case examines the effect of an onboard refueling loss control program on the RVP control measures being examined in this report. Because an onboard rulemaking would likely be running about one year ahead of any evaporative control rule, an onboard implementation date of 1989 was assumed. However, a year's delay in the onboard rulemaking (if decided upon) -- meaning an implementation date of 1990 -- would not be expected to have a great impact on the results of this sensitivity analysis. For all years except 1988 (pre-onboard control), the emission reductions are somewhat lower than under the base case because onboard control would capture a certain percentage of the reductions in refueling losses previously attributed to in-use RVP control. As indicated earlier in Table 6-1, the overall fleetwide efficiency of onboard control (including tampering) will be approximately 94 percent by the year 2010; therefore, emission reductions in the refueling loss category were reduced by this percentage under the onboard sensitivity case. Overall onboard efficiencies assumed for 1990, 1992, 1995, 1997, and 2000 are as follows: 22, 41, 62, 73, and 83 percent, respectively.

The emission reductions, costs, and resulting cost effectiveness estimates for this onboard control sensitivity case are presented in Tables 6-14 through 6-17. As before, both 12-month and 4-month analyses are summarized, and the sensitivity of "R" is also examined. The results of this onboard control sensitivity case are shown graphically for the 12-month analysis in Figures 6-5 and 6-6, with R = 1.0 and R = 0.6, respectively. The effect of implementing onboard refueling controls is a slight worsening of the cost effectiveness for the various RVP control strategies. For example, in the 12-month, R = 1.0 onboard analysis (Table 6-14), the incremental emission reductions in 2010 are roughly 19 percent lower than with the base case (69,000 tons compared to 85,000 tons). Incremental costs are from 3 to 7 percent higher, resulting in a cost/ton that is 28-31 percent higher (depending on RVP scenario).

D. "Without Exhaust Benefits" Case

As discussed in Chapter 2, lower RVP fuels have been shown to produce lower exhaust HC emissions. Based on testing to date, this effect is statistically significant. The base case discussed in Section A above includes these exhaust HC reductions. In order to illustrate the impact of these particular benefits on the cost/ton estimates made in the base case, the sensitivity of eliminating these exhaust HC reductions was examined here.

Table 6-14

"Onboard" Case: 12-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr) Net	Emission Reductions (10^3 Tons/Yr) Incr.	Net Cost* (10^6 \$/Yr) Net	Net Cost* (10^6 \$/Yr) Incr.	Cost Effectiveness (\$/Ton) Net	Cost Effectiveness (\$/Ton) Incr.
11.5	584	584	-160	-160	-274	-274
11.0	653	69	-69	91	-106	1305
10.5	723	70	38	108	53	1550
10.0	792	69	175	137	222	1976
9.5	861	69	318	142	369	2076
9.0	930	69	467	149	502	2147

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons) 1988	1990	1992	1995	1997	2000
11.5-11.0	283	256	210	157	127	98
11.0-10.5	255	230	189	141	116	91
10.5-10.0	216	191	160	121	102	83
10.0- 9.5	193	171	144	113	96	81
9.5- 9.0	169	152	130	104	94	78

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness (\$/Ton)** 1988	1990	1992	1995	1997	2000
11.5-11.0	395	451	258	427	668	828
11.0-10.5	598	700	454	673	954	1164
10.5-10.0	1036	1128	710	992	1306	1503
10.0- 9.5	1200	1359	899	1173	1523	1673
9.5- 9.0	1551	1713	1122	1406	1695	1874

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-15

"Onboard" Case: 4-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	195	195	-155	-155	-799	-799
11.0	218	23	-124	32	-569	1364
10.5	241	23	-81	43	-336	1853
10.0	264	23	-20	61	-74	2652
9.5	287	23	63	83	221	3632
9.0	310	23	157	94	507	4052

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	94	85	70	52	42	33
11.0-10.5	85	77	63	47	39	30
10.5-10.0	72	64	53	40	34	28
10.0-9.5	64	57	48	38	32	27
9.5-9.0	56	51	43	35	31	26

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness ($/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	395	448	267	459	719	941
11.0-10.5	598	706	483	755	1080	1391
10.5-10.0	1036	1131	770	1190	1582	2015
10.0- 9.5	1200	1366	1036	1582	2127	2710
9.5- 9.0	1551	1730	1320	1971	2461	3220

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-16

"Onboard" Case: 12-Month Analysis, R = 0.6

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 \$/Yr)		Cost Effectiveness (\$/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	584	584	-160	-160	-274	-274
11.0	653	69	-41	119	-62	1719
10.5	723	70	104	144	143	2077
10.0	792	69	280	176	354	2541
9.5	861	69	464	184	539	2686
9.0	930	69	658	193	707	2787

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	283	256	210	157	127	98
11.0-10.5	255	230	189	141	116	91
10.5-10.0	216	191	160	121	102	83
10.0- 9.5	193	171	144	113	96	81
9.5- 9.0	169	152	130	104	94	78

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness (\$/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	507	571	400	690	868	1106
11.0-10.5	756	858	641	911	1211	1519
10.5-10.0	1235	1360	982	1337	1666	1982
10.0- 9.5	1437	1621	1200	1540	1906	2163
9.5- 9.0	1839	2026	1477	1830	2113	2412

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-17

"Onboard" Case: 4-Month Analysis, R = 0.6

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 \$/Yr)		Cost Effectiveness (\$/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	195	195	-155	-155	-799	-799
11.0	218	23	-114	41	-525	1778
10.5	241	23	- 59	55	-246	2380
10.0	264	23	15	74	58	3217
9.5	287	23	112	97	391	4242
9.0	310	23	221	109	712	4692

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	94	85	70	52	42	33
11.0-10.5	85	77	63	47	39	30
10.5-10.0	72	64	53	40	34	28
10.0- 9.5	64	57	48	38	32	27
9.5- 9.0	56	51	43	35	31	26

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness (\$/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	507	568	409	641	919	1219
11.0-10.5	756	863	669	993	1336	1746
10.5-10.0	1235	1363	1042	1536	1942	2494
10.0- 9.5	1437	1628	1337	1950	2510	3199
9.5- 9.0	1839	2044	1674	2395	2879	3758

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Figure 6-5

NON-CALIF. EMISSION REDUCTION/COST EFF
WITH ONBOARD

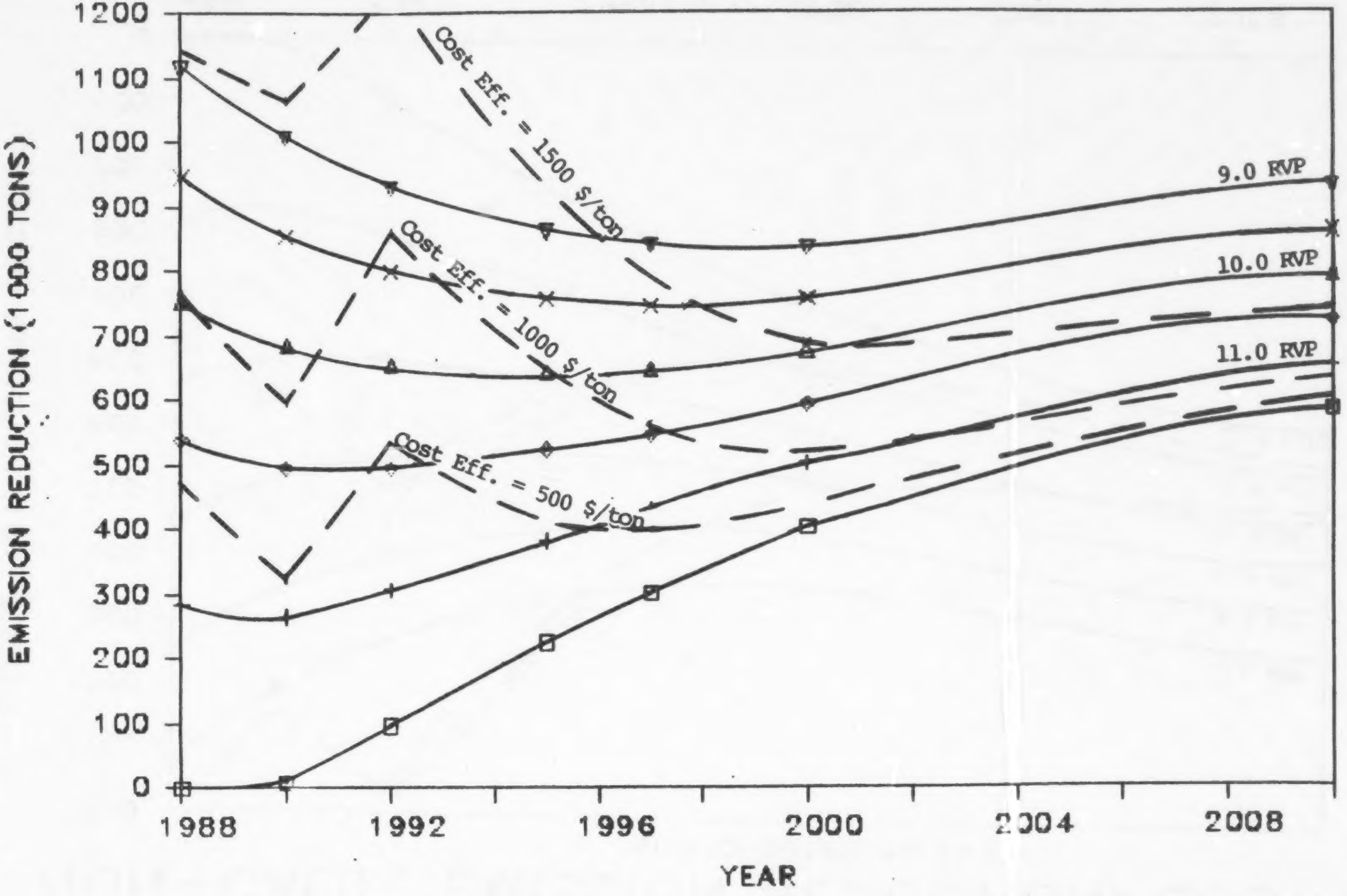
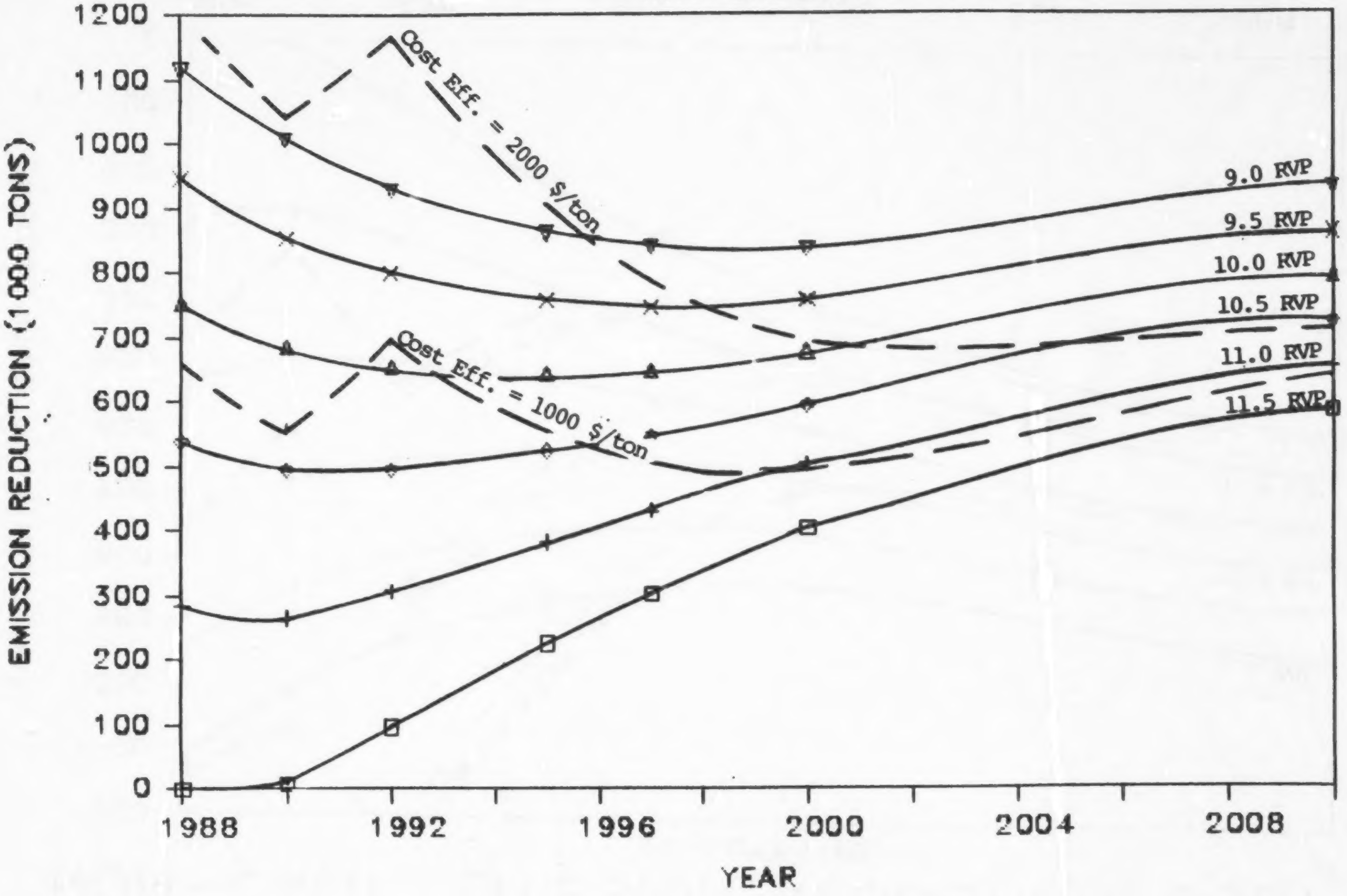


Figure 6-6

NON-CALIF. EMISSION REDUCTION/COST EFF

WITH ONBOARD AND R = 0.6



Tables 6-18 and 6-19 summarize the cost effectiveness, etc., of the various RVP control strategies without benefits in the exhaust HC category. (The sensitivity of the R-value was not evaluated for this case.) The 12-month results are also shown in Figure 6-7. For this sensitivity case, base-case emission reductions were simply reduced by the amount of benefits previously attributed to exhaust emissions. As indicated earlier in Table 6-1, this amount was estimated to be 215,000 tons in 2010; however, for earlier years before the fleet has completely turned over with new vehicles, the tonnage attributed to exhaust reductions varies with RVP. (See details on this in Chapter 2, Section V.) The fuel economy credit due to increased energy content does not change from base case because the same amount of butane is still being removed from the fuel. However, the evaporative recovery/prevention credit is lower with this sensitivity case because the total HC emission reductions used to calculate this credit are lower if exhaust HC reductions are not included. This reduction in overall emission benefits, coupled with the slight increase in overall costs, results in slightly higher net costs per ton. As shown in Tables 6-18 and 6-19, the elimination of exhaust HC benefits predictably increases the short-term $/ton estimates by as much as 27 percent in 1988. However, in the long-term 2010 analysis, 12-month incremental emission reductions and incremental costs are the same as in the base case, so 2010 costs per ton do not change on the increment.

E. "Evaporative I/M Program" Case

The final sensitivity analysis examines the impact an effective inspection and maintenance (I/M) program for evaporative emission controls would have on the cost effectiveness of RVP control strategies. For purposes of this analysis, this evaporative I/M program is assumed to be implemented nationwide by 1988 (the first projection year examined). As discussed earlier, such a program would most likely be initiated only in urban ozone non-attainment areas, but the relative impact would parallel the nationwide analysis in terms of percent reduction in emissions (to be demonstrated below). Through the detection and prevention of certain vehicle problems, the program is assumed to eliminate 70 percent of certain types of malmaintenance and defects and 70 percent of all evaporative system tampering (i.e., missing canisters and missing fuel caps). Contribution of malmaintenance/defects and tampering to the excess evaporative problem are outlined in Chapter 2, Section V. Details of the adjustments made to the evaporative emission rates (including specific problems that can potentially be addressed) under the I/M program are provided in Appendix 6-A at the end of this chapter.

Table 6-18

"No Exhaust" Case: 12-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	369	369	-88	-88	-238	-238
11.0	454	85	- 2	86	- 5	998
10.5	540	86	100	102	184	1197
10.0	625	85	232	132	371	1542
9.5	710	85	368	137	518	1619
9.0	795	85	512	144	644	1681

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	251	227	185	142	121	99
11.0-10.5	222	198	165	128	111	95
10.5-10.0	187	161	134	107	94	85
10.0- 9.5	160	140	120	100	90	82
9.5- 9.0	138	121	106	91	85	81

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness ($/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	492	547	338	508	711	807
11.0-10.5	733	852	569	778	1025	1108
10.5-10.0	1252	1401	895	1158	1443	1445
10.0- 9.5	1515	1700	1157	1375	1650	1652
9.5- 9.0	1977	2225	1453	1643	1882	1801

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-19

"No Exhaust" Case: 4-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	123	123	-83	-83	-673	-673
11.0	151	28	-67	16	-444	555
10.5	180	29	-38	30	-208	1033
10.0	208	28	12	50	58	1757
9.5	236	28	82	70	347	2466
9.0	265	29	172	90	651	3199

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	84	76	62	47	40	33
11.0-10.5	74	66	55	43	37	32
10.5-10.0	62	54	45	36	31	28
10.0- 9.5	53	47	40	33	30	27
9.5- 9.0	46	40	35	30	28	27

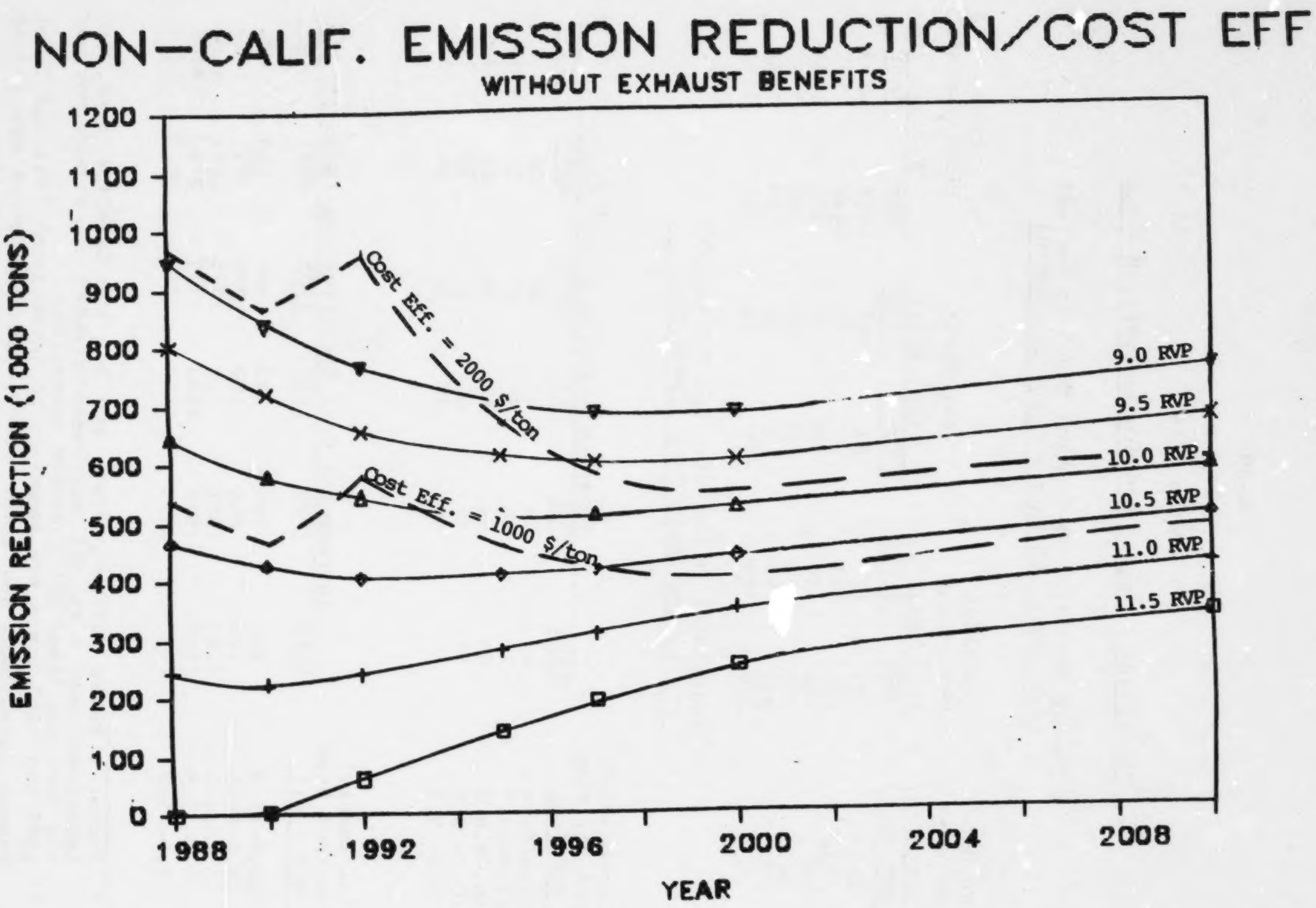
Incremental Control Step RVP (psi)	Incremental Cost Effectiveness ($/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	492	545	323	466	655	688
11.0-10.5	733	846	582	789	1035	1127
10.5-10.0	1252	1401	935	1275	1604	1683
10.0- 9.5	1515	1692	1285	1737	2120	2403
9.5- 9.0	1977	2212	1664	2177	2552	2834

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Figure 6-7


NON—CALIF. EMISSION REDUCTION/COST EFF
WITHOUT EXHAUST BENEFITS
EMISSION REDUCTION (1000 TONS)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1988
1992
1996
2000
2004
2008
YEAR
Cost Eff. = 2000 $/ton
Cost Eff. = 1000 $/ton
9.0 RVP
9.5 RVP
10.0 RVP
10.5 RVP
11.0 RVP
11.5 RVP

Also included in Appendix 6-A is an analysis of the potential effectiveness of an evaporative I/M program such as the one described above. As Table 6-A-7 indicates, extrapolating I/M benefits nationwide (excluding California) could reduce HC emissions by roughly 100,000 tons in 1988 and 343,000 tons in 2010. Looking specifically at the 47 ozone non-attainment areas, HC emissions could be reduced by 39,000 tons in 1988 and by 122,000 tons in 2010 with an effective evaporative I/M program. As alluded to earlier, the 47-city reductions would parallel the non-California reductions in terms of percentage change from baseline, representing a 0.7-percent reduction in total NMHC emissions in 1988 and a 2.2-percent reduction in the year 2010. The overall cost effectiveness ($ per ton) of such an I/M program is estimated at $3780 per ton in the short term (1988) and $1350 per ton in the long term (2010). The development of these emission reductions and costs is outlined in Appendix 6-A.

The sensitivity of the RVP control strategies examined in this study to the implementation of an evaporative I/M program is summarized in Tables 6-20 and 6-21 and Figure 6-8. (For this analysis, "R" was held constant at 1.0.) As indicated in these 12-month and 4-month tables, emission reductions are lower than in the base case because the I/M program will have eliminated portions of motor vehicle evaporative emissions previously reduced by in-use RVP control. (The tonnage reductions attributed to evaporative HC under the evaporative I/M case were compared to the base case for the year 2010 in Table 6-1). Due to these lower emission reductions and the reduced credits for retained evaporative HCs, the cost/ton of RVP control would be significantly higher if an effective evaporative I/M program were implemented prior to RVP control. As shown in Table 6-20, for the long-term 9.0-psi scenario, the incremental cost/ton with an evaporative I/M program would be approximately 66 percent higher than under the base case ($2792 versus $1681 per ton of reduction).

F. Summary

Based on the technical estimates and assumptions used in the base case analysis, purely vehicle-oriented control (i.e., certification fuel RVP revised to 11.5 psi and test procedure modified) appears to be the most cost-effective approach in the long term. As shown earlier for the 12-month analysis in Table 6-6, a total of 584,000 tons of HC emissions can be eliminated via this strategy in the year 2010 at a net savings of roughly $274 per ton to the public. However, because a change in certification fuel and test procedure can only affect vehicle design, strategies involving in-use RVP control can

Table 6-20

"Evap. I/M" Case: 12-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	499	499	-130	-130	-261	-261
11.0	555	56	-36	94	-65	1679
10.5	611	56	76	112	124	2000
10.0	668	57	218	142	326	2491
9.5	722	54	365	147	505	2722
9.0	775	53	513	148	662	2792

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	266	234	189	138	109	81
11.0-10.5	238	207	169	123	100	76
10.5-10.0	210	182	150	111	89	69
10.0- 9.5	186	161	134	102	83	69
9.5- 9.0	162	141	119	93	81	67

Incremental Control Step RVP (psi)	Incremental Cost Effectiveness ($/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	442	523	325	530	827	1071
11.0-10.5	665	812	546	826	1168	1464
10.5-10.0	1077	1214	778	1098	1548	1857
10.0- 9.5	1259	1453	989	1330	1818	2008
9.5- 9.0	1634	1868	1253	1624	2002	2257

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-21

"Evap. I/M" Case: 4-Month Analysis, R = 1.0

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel RVP (psi)	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 \$/Yr)		Cost Effectiveness (\$/Ton)	
	Net	Incr.	Net	Incr.	Net	Incr.
11.5	166	166	-126	-126	-760	-760
11.0	185	19	- 82	44	-441	2397
10.5	204	19	- 37	45	-180	2411
10.0	223	19	28	65	122	3407
9.5	241	18	113	85	468	4733
9.0	258	18	175	62	676	3477

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step RVP (psi)	Emission Reductions (10^3 Tons)					
	1988	1990	1992	1995	1997	2000
11.5-11.0	89	78	63	46	36	27
11.0-10.5	79	69	56	41	33	25
10.5- 9.5	70	61	50	37	30	23
10.0- 9.5	62	54	45	34	28	23
9.5- 9.0	54	47	40	31	26	22

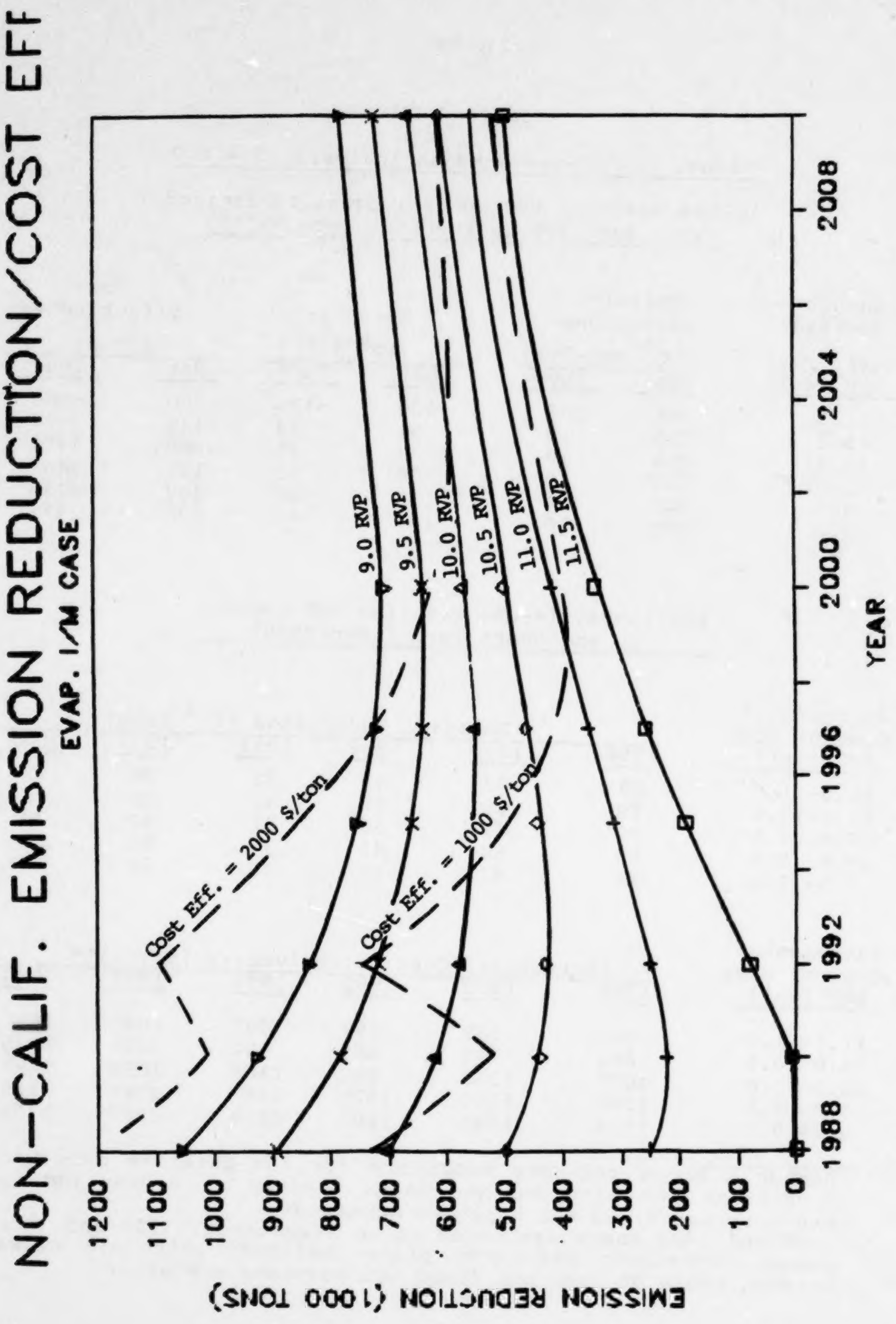
Incremental Control Step RVP (psi)	Incremental Cost Effectiveness (\$/Ton)**					
	1988	1990	1992	1995	1997	2000
11.5-11.0	442	549	390	697	1049	1517
11.0-10.5	665	793	549	904	1326	1725
10.5-10.0	1077	1220	846	1307	1889	2495
10.0- 9.5	1259	1540	1225	1891	2585	3325
9.5- 9.0	1634	1741	1185	1679	2207	2709

---

* Bonner & Moore refinery costs are for the baseline case with investment and with NGL purchases treated as midway between the open and fixed NGL purchase scenarios.

** 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Figure 6-8


NON-CALIF. EMISSION REDUCTION/COST EFF
EVAP. I/M CASE
EMISSION REDUCTION (1000 TONS)
YEAR
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1988
1992
1996
2000
2004
2008
9.0 RVP
9.5 RVP
10.0 RVP
10.5 RVP
11.0 RVP
11.5 RVP
Cost Eff. = 2000 $/ton
Cost Eff. = 1000 $/ton

potentially eliminate additional emissions. This is possible because in-use RVP levels affect those portions of evaporative emissions attributable to malmaintenance/defects and evaporative system tampering, as well as stationary sources such as gasoline storage, distribution, and vehicle refueling, whereas certification fuel RVP has no impact on these emissions. In 2010, year-round in-use fuel RVP control could eliminate up to an additional 426,000 tons of HC emissions at an incremental cost per ton ranging between $998 and $1681 per ton.

In the short term, vehicle-oriented control is relatively ineffective since control is achieved only as the fleet turns over (i.e., roughly seven years are required to obtain half of eventual control). However, since all commercial gasoline would be affected, in-use RVP control is completely effective immediately. For example, HC emission reductions of up to 1,116,000 tons at an incremental cost effectiveness of $395-1551 per ton could be achieved in 1988 with 12-month commercial fuel RVP control.

The above 12-month projections are based on the absence of onboard or Stage II controls and evaporative I/M, and a 100-percent utilization of increased energy density of less-volatile fuels (i.e., R = 1.0). As indicated by the sensitivity analyses, any of these factors could influence these results. Less efficient energy utilization (i.e., R = 0.6) would not affect emission reductions, but would increase costs (because of reduced fuel economy credits); therefore, cost per ton estimates are higher by as much as 35 percent in both the short and long terms. A lower baseline RVP has no effect on incremental emission reductions or costs, so long-term incremental cost effectiveness is not affected. An onboard control program reduces incremental emission benefits and slightly increases incremental costs, so the incremental cost per ton is increased by as much as 31 percent. Finally, a maximally effective evaporative I/M program would have little effect on vehicle-oriented control programs, but would have a fairly significant impact on in-use RVP control, reducing long-term incremental emission reductions by 34 percent and raising long-term incremental cost per ton by as much as 68 percent over the base case estimates.

References (Chapter 6)

1. "Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry," U.S. EPA, Office of Air and Radiation, EPA-450/3-84-012, July 1984.

2. "The Feasibility, Cost, and Cost Effectiveness of Onboard Vapor Control," Glenn W. Passavant, U.S. EPA/OAR/OMS/ECTD/SDSB, EPA-AA-SDSB-84-01, March 1984.

3. "Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles," U.S. EPA/OAR/OMS/ECTD/TSS, EPA-AA-TSS-83-10, December 31, 1983.

4. "MOBILE3 Fuel Consumption Model," Mark A. Wolcott, EPA, and Dennis F. Kahlbaum, CSC, February 1985.

5. "The Highway Fuel Consumption Model: Tenth Quarterly Report," Energy and Environmental Analysis, Inc., for U.S. Department of Energy, November 1983.

6. "Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles," EPA-AA-TSS-83-10, December 31, 1983.

7. "Reoccurrence of Evaporative System Malmaintenance and Tampering," EPA memo from David J. Brzezinski to Phil Carlson, October 4, 1985.

8. "MOBILE3 Fuel Consumption Model," Mark A. Wolcott, EPA, and Dennis F. Kahlbaum, CSC, February 1985.

Appendix 6-A

Evaluation of an Inspection/Maintenance Program for Evaporative Emission Control Systems

This appendix details the calculations used to derive the effectiveness and cost effectiveness of an inspection/maintenance (I/M) program for evaporative emission control systems. The program was assumed to begin in 1988 as this was the assumed year of implementation for in-use RVP control and is also likely the earliest feasibile implementation date for evaporative I/M. Application was restricted to 1978 and later model year LDVs and LDTs, as earlier vehicles were not certified using the comprehensive SHED test. Their evaporative emission control systems are not very effective and are not amenable to cost-effectiveness repair. Heavy-duty vehicles were not included as current I/M programs for exhaust emissions generally do not include HDVs.

The first section of this appendix will describe how the evaporative emission reductions were estimated. The second section will present the costs associated with the I/M program, and the last section will present the cost effectiveness results for 1988 and 2010, representative of the long-run.

Evaporative I/M Emission Reductions

The total emission reductions obtainable through an evaporative I/M program were based on the results of EPA's in-use emission factors (EF) test program, which is described in Chapter 2. Tables 6-A-1 and 6-A-2 present the types of malmaintenance and defect (M&D) problems checked and discovered in the EF test program and the rate of occurrence of each problem for fuel-injected (FI) and carbureted vehicles, respectively. Tables 6-A-1 and 6-A-2 also present the average diurnal and hot-soak emission effect associated with each problem, as measured in the EF test program vehicles, on Indolene and commercial fuels.

The percentage of the total M&D effect due to each defect is contained in Tables 6-A-3 and 6-A-4 for fuel-injected and carbureted vehicles, respectively. The percentages were calculated using the following equation and then normalized. (All negative percentage contributions, due to presumedly anomalous emission improvements, were assumed to be zero before the total percentage was normalized.)

$$\frac{\text{Avg Evap Emissions due to M\&D Problem} - \text{Problem Free Emissions}}{\text{Total M\&D Effect}} \times \text{Rate of Occurrence of M\&D Problem} = \text{Percent of M\&D Problem due to Defect}$$

Table 6-A-1

In-Use EF Test Program M&D Types, Rates of Occurrence, and Diurnal/Hot Soak Emissions for Fuel-Injected Vehicles

			Avg. Evap. Emissions (g/test)			
			Indolene		Commercial	
Defect	No. of Vehicles	Rate* (%)	DI	HS	DI	HS
Gas Cap Leak	2	3.6	5.25	2.13	14.75	6.49
Air Cleaner Gasket Broken/ Missing	2	3.6	3.62	5.92	14.00	13.21
Canister Filter Dirty	2	3.6	2.24	0.60	5.59	2.66
Canister Saturated w/Liquid Fuel	1	1.8	3.38	2.14	11.84	1.93
Canister Broken	1	1.8	0.98	1.67	2.14	13.06
Problem Free Emissions			0.87	0.64	4.67	0.90
Total M&D Effect			0.34	0.29	0.84	0.93

---

* Fifty-five fuel injected vehicles tested.

Table 6-A-2

In-Use EF Test Program M&D Types, Rates of Occurrence, and Diurnal/Hot Soak Emissions for Carbureted Vehicles

			Avg. Evap. Emissions (g/test)			
			Indolene		Commercial	
Defect	No. of Vehicles	Rate* (%)	DI	HS	DI	HS
Gas Cap Leak	6	5.5	8.29	2.89	14.45	4.96
Canister Filter Dirty	1	0.9	3.45	1.40	17.67	1.55
Canister Saturated w/Liquid Fuel	7	6.4	3.50	2.29	12.25	2.68
Canister Broken	0	0	-	-	-	-
EFE TVS Stuck	1	0.9	6.90	1.50	3.52	2.83
Bowl Vent Value Stuck	1	0.9	1.68	1.25	16.61	1.15
Vacuum Line Damaged	6	5.5	6.79	4.06	16.66	6.05
Vacuum Line Plugged	1	0.9	2.15	9.72	9.76	3.42
Bowl Vent Line Damaged	1	0.9	1.89	5.00	3.77	6.41
VCV Inoperative	1	0.9	1.34	5.16	16.63	4.13
Purge Solenoid/ Value Sticking	3	2.8	2.24	4.70	8.70	7.70
Purge Solenoid/ Value Inoperative	1	0.9	3.73	13.78	3.72	15.94
Purge Solenoid/ Value Leaks Vacuum	2	1.8	3.90	5.25	22.96	7.38
Rollover Valve Leaking	1	0.9	10.35	6.27	22.55	11.69
Carburetor Leaks Fuel	1	0.9	0.58	13.82	3.40	10.57
Carburetor Exceptionally Dirty	2	1.8	1.90	1.51	16.29	2.15
Problem Free Emissions			1.25	1.50	7.40	2.60
Total M&D Effect			1.11	0.83	1.61	1.24

---

* 109 carbureted vehicles tested.

Table 6-A-3

Normalized Percentages of Total M&D Effect Due to Specific M&D Problems on Fuel-Injected Vehicles

	Indolene		Commercial	
Defect	DI	HS	DI	HS
Gas Cap Leak*	44.6	18.6	42.1	21.3
Air Cleaner Gasket Broken/ Missing*	28.0	65.7	39.0	46.8
Canister Filter Dirty	14.0	-	3.9	6.7
Canister Saturated w/Liquid Fuel	12.8	9.3	15.0	1.9
Canister Broken*	0.6	6.4	-	23.3
Total	100.0	100.0	100.0	100.0
Total Percentage Addressable w/ I/M	73.2	90.7	81.1	91.4

---

* Addressable through an evaporative I/M program.

- Indicates the defects had a negative M&D effect before normalization of the total, and was eliminated.

Table 6-A-4

Normalized Percentages of Total M&D Effect Due to Specific M&D Problems on Carbureted Vehicles

	Indolene		Commercial	
Defect	DI	HS	DI	HS
Gas Cap Leak*	34.5	9.1	18.3	14.6
Canister Filter Dirty	1.8	-	4.5	-
Canister Saturated w/Liquid Fuel	12.9	6.1	14.7	0.6
EFE TVS Stuck	4.6	0	-	0.3
Bowl Vent Value Stuck	0.4	-	4.0	-
Vacuum Line Damaged*	27.2	16.9	24.1	21.3
Vacuum Line Plugged	0.7	9.0	1.0	0.8
Bowl Vent Line Damaged*	0.5	3.9	-	3.9
VCV Inoperative	0.1	4.0	4.0	1.5
Purge Solenoid/Valve Sticking	2.5	10.5	1.7	15.8
Purge Solenoid/Valve Inoperative	2.0	13.5	-	13.8
Purge Solenoid/Valve Leaks Vacuum	4.3	8.2	13.5	9.9
Rollover Valve Leaking	7.4	5.3	6.5	9.3
Carburetor Leaks Fuel*	-	13.5	-	8.2
Carburetor Exceptionally Dirty	1.1	0	7.7	-
Total	100.0	100.0	100.0	100.0
Total Percentage Addressable w I/M	62.2	43.4	42.4	48.0

---

* Addressable through an evaporative I/M program.

- Indicates the defect had a negative M&D effect before normalization of the total, and was eliminated.

Tables 6-A-3 and 6-A-4 also contain the maximum percentage of the M&D effect addressable through an evaporative I/M program broken down into the diurnal and hot-soak components. Leaking gas caps, missing or broken carburetor gaskets, broken canisters and damaged hoses are assumed to be detectable for signs of defects. To detect a leaky gas cap, the fuel tank is sealed off, pressurized through its connection to the charcoal canister and allowed to sit for five minutes. A drop in pressure noted with a pressure gauge indicates a possible leaking gas cap. To detect a broken/missing gasket, propane is sprayed around the intake manifold in an engine at idle. An increase in engine RPM indicates a broken/missing gasket. Broken canisters and damaged hoses are detected visually. Table 6-A-5 contains the maximum portion of M&D effects addressable through an evaporative I/M program which is 100 percent effective. (The rates are an average of the percentage reductions obtainable on Indolene and commercial fuels shown in Tables 6-A-3 and 6-A-4.) I/M programs are generally projected to be 70 percent effective.[6] Thus, potential M&D effect emission reductions should be reduced by 30 percent to reflect more realistic I/M effectiveness (also listed in Table 6-A-5).

Table 6-A-6 contains tampering problems and rates of tampering expected in an evaporative I/M program. Gas caps, canisters and connecting hoses which have been removed or disconnected are considered to be tampering. An evaporative I/M program is also expected to be 70 present effective in the detection of tampering problems.

Based on these 70-percent emission reductions in addressable M&D excess emissions effects, and a 70 percent reduction in tampering excess emissions effects, new emissions factors were calculated and used to run the MOBILE3 computer program. The MOBILE3 results were used in determining the non-California emissions inventory according to the methodology described in Chapter 5. The total non-California NMHC emission reductions obtained with an evaporative I/M program at 70 percent effectiveness, with in-use fuel at 11.5 psi RVP, and certification fuel at 9.0 psi RVP are contained in Table 6-A-7. The total 47 ozone non-attainment cities NMHC emission reductions are also contained in Table 6-A-7. An evaporative I/M program would only be instituted in cities with I/M programs for exhaust emissions. These are best represented by

Table 6-A-5

Portion of M&D Effects Addressable Through Evaporative I/M (Percent)

Vehicle Type	@ 100% Effectiveness DI*	@ 100% Effectiveness HS*	@ 70% Effectiveness DI	@ 70% Effectiveness HS
FI	77.2	91.1	54.0	63.7
Carb	52.3	45.7	36.6	32.0

---

* Rates are average of percentage reductions obtainable on Indolene and Commercial fuels listed in Tables 6-A-3 and 6-A-4.

Table 6-A-6

Tampering Types of Problems and Rates of Occurrence

Problem	Rate of Occurrence (%)
Gas Cap Removed	1.2
Canister Vacuum Disconnected	1.7
Cap Removed & Canister Vacuum Disconnected	0.1
Canister Removed	0.3
Canister Mechanically Disconnected	0.2

Table 6-A-7

Total NMHC Emission Reductions Obtainable with a 70% Effective Evaporative I/M Program (1000 tons/year)

Non-California Scenario	Year 1988	1990	1992	1995	1997	2000	2010
Baseline*	14307	13821	13513	13350	13397	13642	15298
Baseline* w/Evap I/M	14207	13634	13293	13094	13124	13350	14955
Reduction due to Evap I/M	100	187	220	256	273	292	343

47 Non-Attainment Cities Scenario	Year 1988	1990	1992	1995	1997	2000	2010
Baseline*	5592	4879	4757	4699	4716	4816	5461
Baseline* w/Evap I/M	5553	4813	4679	4609	4620	4713	5339
Reduction due to Evap I/M	39	66	78	90	96	103	122

---

* Baseline refers to In-use fuel at 11.5 psi RVP and Certification fuel at 9.0 psi RVP.

the 47 ozone non-attainment cities, so the last set of emission reductions is most pertinent. However, non-California emission reductions assuming evaporative I/M programs are instituted everywhere, are presented since nationwide emission effects are most commonly available for other control programs. The non-California figures here can then be used to compare relative effectiveness with those programs, realizing that the control is only available in areas with exhaust emission I/M programs.

Evaporative I/M Costs

The costs of an evaporative I/M program arise from the two steps of an I/M program, the inspection and the repair of the malmaintained, defective and/or tampered parts. The cost per inspection assumes a three minute inspection per vehicle (in addition to the time required for an exhaust inspection) at a labor rate of $20/hour. The increase in time is primarily due to the procedure to check for leaky gas caps. This results in an incremental inspection cost per vehicle of $1.00.

Table 6-A-8 contains the estimated costs of the parts and the amount of time necessary to carry out the repairs. The part costs are based on typical costs of parts found in "Mitchells Mechanical Parts/Labor Estimating Guides" and the labor costs are based on a basic shop fee of $35/hour. The repair costs associated with each problem for fuel-injected and carbureted vehicles on both a repaired vehicle and average in-use vehicle basis are listed in Tables 6-A-9 and 6-A-10. Inspection and total inspection and repair costs are shown as well.

The total first year repair cost is greater than the total second (and later) year repair cost. This occurs because during the first year of the evaporative I/M program (1988), all of the vehicles from model years back to 1978 must be repaired. In the second and subsequent years, only the cars which have had malmaintenance and defect problems and/or have been tampered with within the last year need to be repaired. A reoccurrence rate of 60 percent was assumed.[7] Thus, the second year (and later) repair costs are 60 percent of the first year repair costs. The incremental inspection cost remains unchanged since all vehicles must still be inspected.

An economic credit is realized from the emission reductions derived from the evaporative I/M program. The excess emissions which would have been lost without repairs to the evaporative control system, will now be captured by the charcoal canister and combusted in the engine. The economic credit is determined as explained previously in Chapter 4, Section VI by assuming the composition of the emissions is all

Table 6-A-8

Evaporative I/M Parts and Labor Repair Costs

Part Replaced	Cost($)	Hours of Labor*	Total Cost($)
Gas Cap	10	-	10.00
Intake Gasket	10	3.0	115.00
Evaporative Canister Hose	2	0.3	12.50
Carburetor Gasket	40	1.4	89.00

---

* Labor time was estimated based on "Mitchell Mechanical Parts/Labor Estimating Guides" for Domestic Cars 1984 and Imported Cars and Trucks 1984. Published by Mitchell Manuals, Inc., San Diego, California, 1984. A basic shop fee of $35/hour labor cost was used.

Table 6-A-9

Evaporative I/M Cost per Vehicle Inspected for Fuel-Injected Vehicles

M&D Problem	Rate(%)	Repair Cost($)	Repair Cost /Vehicle($)
Leaking Gas Cap	3.6	10.00	0.36
Leaking Gasket	3.6	115.00	4.14
Broken Canister	1.8	67.50	1.22
Tampering Problem			
Gas Cap Removed	1.2	10.00	0.12
Canister Vacuum Disconnected	1.7	12.50	0.21
Cap Removed & Canister Vacuum Disconnected	0.1	22.50	0.02
Canister Removed	0.3	67.50	0.20
Canister Mechanically Disconnected	0.2	12.50	0.03
Repair Cost			6.30

First Year Repair Cost (at 70% effectiveness)	4.41
Incremental Inspection Cost	1.00
Total First Year Repair & Inspection Cost per vehicle	5.41
Second year(+) Repair Cost (at 70% effectiveness)	2.65
Incremental Inspection Cost	1.00
Total Second Year Repair and Inspection Cost per vehicle	3.65

Table 6-A-10

Evaporative I/M Cost per Vehicle Inspected for Carbureted Vehicles

M&D Problem	Rate(%)	Repair Cost($)	Repair Cost /Vehicle($)
Leaking Gas Cap	5.5	10.00	0.55
Damaged Vacuum Line	5.5	12.50	0.69
Damaged Vent Line	0.9	12.50	0.11
Leaking Carburetor	0.9	89.00	0.80
Tampering Problems			
Gas Cap Removed	1.2	10.00	0.12
Canister Vacuum Disconnected	1.7	12.50	0.21
Cap Removed & Canister Vacuum Disconnected	0.1	22.50	0.02
Canister Removed	0.3	67.50	0.20
Canister Mechanically Disconnected	0.2	12.50	0.03
		Repair Cost	2.73
First Year Repair Cost (at 70% effectiveness)			1.91
Incremental Inspection Cost			1.00
Total First Year Repair & Inspection Cost per vehicle			2.91
Second Year(+) Repair Cost (at 70% effectiveness)			1.15
Incremental Inspection Cost			1.00
Total Second Year Repair & Inspection Cost per vehicle			2.15

butane. (Table 4-12 contains the values used to convert the butane to a gasoline equivalent and then to economic credits.) Tables 6-A-11 and 6-A-12 contain the fuel recovery credits for the evaporative I/M program for 1988 and 2010, respectively.

Evaporative I/M Cost Effectiveness

Tables 6-A-11 and 6-A-12 present the derivation of the cost effectiveness (C/E) of an evaporative I/M program in 1988 (first year) and 2010, respectively. Both Tables 6-A-11 and 6-A-12 utilize nationwide costs as these are the most readily available and nationwide emission reductions. However, this has no effect on the final cost-effectiveness of any particular evaporative I/M program since a city's fraction of nationwide vehicles should be the same as its fraction of nationwide NMHC emissions. Therefore, the cost effectiveness numbers can be applied to any of the 47 non-attainment cities where the evaporative I/M program could be implemented.

The total number of vehicles affected by an evaporative I/M program were based on the MOBILE3 fuel consumption model [8] and MOBILE3 carbureted and fuel-injected projections back to 1978 (for the 1988 analysis), and back to 1990 (for the 2010 analysis). The I/M cost without the fuel recovery credit is a weighted-average of the total inspection and repair cost for fuel-injected and carbureted vehicles. The fuel recovery credit, as described in the previous section, is subtracted from the inspection and repair cost to obtain the I/M cost with the fuel recovery credit. The I/M cost with the fuel recovery credit is the final cost of the evaporative I/M program and is divided by the emission reductions listed in Table 6-A-7 to determine the C/E of the evaporative I/M program. The resulting C/E numbers are $3780/ton in 1988 and $1350/ton in 2010.

Table 6-A-11

1988 Cost Effectiveness of Evaporative I/M

Total number of nationwide vehicles affected by I/M program[1]:

	FI	Carb.
LDV:	38.6×10^6	57.6×10^6
LDT:	5.9×10^6	17.9×10^6
Total	44.5×10^6	75.5×10^6

Cost of Inspection and Repair per Vehicle (first year):

FI = \$5.41 Carb. = \$2.91

Nationwide Cost of Inspection and Repair: $\$4.60 \times 10^8$

Nationwide Fuel Recovery Credit[2]: $\$0.37 \times 10^8$

Nationwide I/M Cost with Fuel Recovery Credit: $\$4.23 \times 10^8$

Nationwide Emission Reduction due to I/M: 112,000 tons

Cost Effectiveness: $\frac{\$4.23 \times 10^8}{112{,}000 \text{ tons}} = \$3780/\text{ton}$

---

[1] Based on MOBILE3 fuel consumption model total number of vehicles and MOBILE3 vehicle registration distributions and carbureted and fuel injected projections back to 1978.

[2] Fuel recovery credit was determined assuming the recovered emissions were butane.

Table 6-A-12

2010 Cost Effectiveness of Evaporative I/M

Total number of nationwide vehicles affected by I/M program[1]:

	FI	Carb.
LDV:	135.6×10^6	17.1×10^6
LDT:	30.0×10^6	3.8×10^6
Total	165.6×10^6	20.9×10^6

Cost of Inspection and Repair per Vehicle (second and later years):

FI = \$3.65 Carb. = \$2.15

Nationwide Cost of Inspection and Repair:	$\$6.49 \times 10^8$
Nationwide Fuel Recovery Credit[2]:	$\$1.28 \times 10^8$
Nationwide I/M Cost with Fuel Recovery Credit:	$\$5.21 \times 10^8$
Nationwide Emission Reduction due to I/M:	385,000 tons

Cost Effectiveness: $\frac{\$5.21 \times 10^8}{385{,}000 \text{ tons}} = \$1350/\text{ton}$

---

[1] Based on MOBILE3 fuel consumption model. Since evaporative I/M program would cover last 20 model years, essentially all LDVs and LDTs would be covered.

[2] Fuel recovery credit was determined assuming the emissions were butane.

Appendix 6-B

Effects of Increased Canister Size on Operating Costs

There will be a very slight reduction in fuel economy associated with the increased weight of the canister in the modified evaporative control system. This will affect a vehicle's operating cost, and must therefore be included in the total costs associated with the proposed changes to the certification test procedure. The calculation of this weight penalty will be the subject of this appendix. Key values used in these calculations are summarized in Table 6-B-1.

Appendix 3-A described how the component costs for each certification fuel RVP were calculated. The weight associated with each component of an 850-ml canister is given in Table 3-A-5. By scaling up these component weights, as was done for the costs (described in Appendix 3-A), the increased canister weight associated with each certification fuel RVP can be determined. These are provided in Table 6-B-2.

These weight increases can be expressed as a percentage of the total weight of the vehicle using the estimates of total vehicle weights shown in Table 6-B-1. Estimated weight sensitivity factors, which relate a percentage increase in weight to a percentage reduction in fuel economy, and class-average fuel economies are also given in Table 6-B-1 and are used along with the percentage weight increases to determine the expected reductions in fuel economy. These reductions in fuel economy are then coupled with estimates of lifetime vehicle mileages (shown in Table 6-B-1) to calculate the extra gallons of fuel used over the vehicle's life. These lifetime mileages are discounted (at 10 percent per annum) to represent the fact that a dollar saved in the tenth year of vehicle use is not the same as one saved in the first year. The net cost to the consumer is then determined using a fuel cost of $0.98 per gallon. Table 6-B-2 summarizes the calculated values for reduction in fuel economy, extra gallons of fuel, and cost.

Table 6-B-1

Summary of Values Used in Calculation

	LDV	LDT	HDV
Fuel Economy (mpg)*	26.64	18.97	10.39
Vehicle Weight (lb)**	3082	3832	9270
Weight Sensitivity Factor (% change in fuel economy per % change in weight)***	0.329	0.402	0.450
Discounted Lifetime Mileage****	65,400	80,900	71,700

---

* 1994 values from "MOBILE3 Fuel Consumption Model," Mark A. Wolcott, EPA, and Dennis F. Kahlbaum, CSC, February 1985.

** "Light-Duty Auto Fuel Economy...Trends Through 1985," Heavenrich, Murrell, Cheng and Loos, SAE 850550.

*** "Analysis Memorandum: Design Factor Update," prepared by Energy and Environmental Analysis, Inc., for EPA, October 1, 1982.

**** "Regulatory Impact Analysis, Oxides of Nitrogen Pollutant Specific Study and Summary and Analysis of Comments," EPA/OAR/OMS, March 1985. (Discounted at 10 percent over life of vehicle.)

Table 6-B-2

Values of Weight Increase, Penalty Factor, and Weight Penalty for Various Certification Fuels

Class	Certification Fuel RVP(psi)				
	9.5	10.0	10.5	11.0	11.5
LDV					
Increased Weight(lb)	0.16	0.32	0.48	0.64	0.81
Reduced Fuel Economy (gal/mi X 10^2)	0.04	0.09	0.14	0.18	0.23
Extra Fuel (gal/vehicle life)	0.04	0.08	0.13	0.17	0.21
Cost* ($/vehicle)	0.04	0.08	0.12	0.16	0.20
LDT					
Increased Weight(lb)	0.20	0.39	0.59	0.80	0.98
Reduced Fuel Economy (gal/mi x 10^2)	0.04	0.08	0.12	0.16	0.20
Extra Fuel (gal/vehicle life)	0.09	0.17	0.26	0.36	0.44
Cost* ($/vehicle)	0.09	0.17	0.26	0.35	0.43
HDV					
Increased Weight(lb)	0.42	0.83	1.25	1.67	2.10
Reduced Fuel Economy (gal/mi X 10^2)	0.02	0.04	0.06	0.08	0.11
Extra Fuel (gal/vehicle life)	0.14	0.28	0.42	0.56	0.70
Cost* ($/vehicle)	0.14	0.27	0.41	0.55	0.69

---

* Using $0.98/gallon

Appendix 6-C

Development of Non-Summer Evaporative Emission Recovery Credits for Four-Month Analyses

Cost calculations for the 4-month analysis must take into account the fact that vehicle-related effects occur year-round while commercial fuel-related effects occur during the 4-month period only. Thus, refinery costs and the fuel economy credit due to the increased energy content of commercial gasoline are simply one-third of the annual cost since these effects only appear when volatility control is operative. Vehicle redesign costs and the associated weight penalty are equivalent to the annual cost since these are unaffected by the removal of in-use RVP controls. The derivations of the individual vehicle- and fuel-related control costs are provided in Chapters 3 and 4, respectively. Determining the evaporative prevention/recovery credit is not as straightforward, however, and this is the focus of this appendix.

During the summer period the evaporative credit is simply one-third of the year-round figure since both fuel and vehicle controls are in place. However, since vehicle controls operate year-round, additional emission recovery occurs during the non-summer period even when the fuel controls are inoperative. These non-summer emission reductions were estimated by running MOBILE3 to simulate a commercial fuel RVP of 11.5 psi (i.e, no in-use RVP control) with certification fuel volatilities varying between 9.5 and 11.5 psi RVP (i.e., various levels of vehicle control). The evaporative and exhaust HC emission factors used as input to these MOBILE3 runs are described below. Only post-1989 model year vehicles are affected, since 1990 model year vehicles are assumed to be the first to be affected by changes to certification fuel and/or test procedure. Pre-1990 emission rates were the same as the baseline case (certification fuel of 9.0-psi RVP with in-use fuel of 11.5-psi RVP).

As described in Chapter 2, motor vehicle evaporative emissions can be attributed to emissions from properly designed and operating systems and excess emissions due to: 1) insufficient design of the purge system; 2) malmaintenance and equipment defects; 3) commercial fuel RVP in excess of certification fuel RVP; and 4) evaporative control system tampering. The size of each of these sources (except for tampering, which is handled separately) as a function of RVP was estimated in Section V of Chapter 2 (Table 2-15) and summarized in Tables 5-1 and 5-2 of Chapter 5. There, in-use and certification fuel RVP changed simultaneously or in-use RVP was varied while certification fuel RVP was held at 9.0 psi. Each of these sources will be re-estimated here under the different condition of unchanging in-use fuel RVP, but varying certification fuel RVP.

Tables 6-C-1 through 6-C-3 summarize the estimates of each of these sources and total non-tampered emissions for post-1989 light- and heavy-duty vehicles. Emission factors for properly designed and operating vehicles are not a function of RVP. Thus, they were taken directly from Tables 5-1 and 5-2. The effect of improper design was assumed in Chapter 2 to disappear with revision of the evaporative emission test procedure, again irrelevant of in-use or certification RVP. Thus, its level is zero throughout Tables 6-C-1 through 6-C-3. The effect of malmaintenance and defects was shown in Chapter 2 to be dependent only upon in-use RVP. As in-use RVP is constant at 11.5 psi here, the effect of malmaintenance and defects is that from Table 2-15 for 11.5-psi RVP at all certification fuel RVP levels. The RVP effect described in Chapter 2 was described as being a function of the difference between certification and in-use RVP. Table 2-15 shows this effect for in-use RVP values between 9.0 and 11.5 psi with certification RVP held constant at 9.0 psi, or in other words, for RVP differences of 0-2.5 psi. These results were simply transposed to apply here where the certification RVP varied and in-use RVP remained at 11.5 psi. For example, the RVP effect during the non-summer period for a certification RVP of 9.5 psi (difference of 2.0 psi RVP) was taken to be that shown in Table 2-15 corresponding to 11.0 psi RVP for in-use fuel.

Also relevant is the exhaust emission effect. Chapter 2 discusses EPA's test results which show fuel RVP to have an effect on exhaust HC and CO emissions. This effect on emissions was accounted for in the analysis in Chapter 5 by applying multiplicative factors for each RVP scenario to the original MOBILE3 exhaust emission factors. These multiplicative adjustment factors are shown in Tables 5-10 and 5-11. For the non-summer scenario, the adjustment factors were assumed to vary with the in-use/certification fuel RVP differences like that used above to determine the RVP effect during the non-summer period (i.e., in proportion to the difference between in-use and certification RVP).

Given the above inputs, the reductions in evaporative HC emissions were determined from MOBILE3 runs. This emission reduction was multiplied by 0.67 to obtain the evaporative emission recovery credit in the eight-month non-summer period. The methodology for calculating an annual credit for these reductions is the same as that for the 12-month analysis and is outlined in detail in Section VI of Chapter 4. Table 6-C-4 summarizes the long-term costs and credits of the base case for both the 12-month and 4-month analyses.

Table 6-C-1

Diurnal Emissions (g/test) from Non-Tampered Post-1989 LDVs and LDTs for Non-Summer Period (In-Use RVP Constant at 11.5 psi)

	Certification RVP (psi)				
	9.5	10.0	10.5	11.0	11.5
Carbureted Vehicles					
Properly Designed and Operated	0.91	0.91	0.91	0.91	0.91
Improper Design	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect	1.61	1.61	1.61	1.61	1.61
RVP Effect	4.33	2.78	1.54	0.62	0.00
Total	6.85	5.30	4.06	3.14	2.52
Fuel-Injected Vehicles					
Properly Designed and Operated	0.91	0.91	0.91	0.91	0.91
Improper Design	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect	0.84	0.84	0.84	0.84	0.84
RVP Effect	2.03	0.79	0.48	0.24	0.00
Total	3.78	2.54	2.23	1.99	1.75

Table 6-C-2

Hot-Soak Emissions (g/test) from Non-Tampered
Post-1989 LDVs and LDTs for
Non-Summer Period (In-Use RVP Constant at 11.5 psi)

	Certification RVP (psi)				
	9.5	10.0	10.5	11.0	11.5
Carbureted Vehicles					
Properly Designed and Operated	1.09	1.09	1.09	1.09	1.09
Improper Design	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect	1.24	1.24	1.24	1.24	1.24
RVP Effect	0.73	0.42	0.20	0.06	0.00
Total	3.06	2.75	2.53	2.39	2.33
Fuel-Injected Vehicles					
Properly Designed and Separated	0.61	0.61	0.61	0.61	0.61
Improper Design	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect	0.93	0.93	0.93	0.93	0.93
RVP Effect	0.24	0.18	0.11	0.05	0.00
Total	1.78	1.72	1.65	1.59	1.54

Table 6-C-3

Diurnal and Hot-Soak Emissions (g/test) from Non-Tampered Post-1989 HDVs for Non-Summer Period (In-Use RVP Constant at 11.5 psi)

	Certification RVP (psi)				
	9.5	10.0	10.5	11.0	11.5
Diurnal Emissions					
Properly Designed and Operated	1.44	1.44	1.44	1.44	1.44
Improper Design	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect	2.57	2.57	2.57	2.57	2.57
RVP Effect	6.90	4.43	2.46	0.98	0.00
Total	10.91	8.44	6.47	4.99	4.01
Hot-Soak Emissions					
Properly Designed and Operated	1.73	1.73	1.73	1.73	1.73
Improper Design	0.00	0.00	0.00	0.00	0.00
Malmaintenance and Defect	1.97	1.97	1.97	1.97	1.97
RVP Effect	1.15	0.67	0.31	0.09	0.00
Total	4.85	4.37	4.01	3.79	3.70

Table 6-C-4

Costs and Credits for "Base Case" in 2010 ($ million/yr.)

12-Month Analysis

	In-Use/Cert. RVP (psi)					
	11.5	11.0	10.5	10.0	9.5	9.0
Refinery Cost	0	192	421	686	962	1256
Fuel Econ. Credit	0	88	200	320	448	584
Vehicle Cost	28	23	18	14	9	0
Weight Penalty	8	7	5	3	2	0
Evap. Recovery	240	275	310	346	381	416
Total Cost	-240	-141	-66	37	144	256

4-Month Analysis

	In-Use/Cert. RVP (psi)					
	11.5	11.0	10.5	10.0	9.5	9.0
Refinery Cost	0	64	140	229	321	419
Fuel Econ. Credit	0	29	67	107	149	195
Vehicle Cost	28	23	18	14	9	0
Weight Penalty	8	7	5	3	2	0
Evap. Credit:						
Summer Period	78	104	123	136	139	137
Winter Period	156	136	113	89	49	0
Total Cost	-199	-175	-140	- 86	- 6	87